PB81-175929

Batch Pretreatment Process Technology for Abatement of Emissions and Conservation of Energy in Glass Melting Furnaces
Phase I. Process Design Manual

Corning Glass Works, NY

Prepared for

Industrial Environmental Research
Lab.-Cincinnati, OH

Mar 81

U.S. Department of Commerce
National Technical Information Service

[redacted]

PB81-175929

EPA 600/7-81-038
March 1981

BATCH PRETREATMENT PROCESS
Technology For Abatement of Emissions and Conservation of Energy in Glass Melting Furnaces
Phase I Process Design Manual

by

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Contract #68-02-2640

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

BIBLIOGRAPHIC INFORMATION

PB81-175929

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PERFORMER: Corning Glass Works, NY.
Contract EPA-68-02-2640

SPONSOR: Industrial Environmental Research Lab.-Cincinnati, OH.
EPA-600/781-038

The Environmental Protection Agency contracted with Corning Glass Works for the development of glass batch pretreatment process which would abate emissions and reduce energy usage in the melting furnace. The contract consists of two phases of work. Phase I, now completed and reported in this document, was a laboratory phase to supply the information needed to design a pilot plant system, and based on this design, to estimate the energy, pollution, and economic advantages of the program. Phase II will consist of constructing and operating a batch preheating pilot plant test facility to confirm the bench scale test results and to provide the necessary design and operating information for a full scale production facility. The Phase II results will also be used to update the energy, pollution, and economic advantages of the process.

KEYWORDS: *Air pollution control, *Energy conservation, *Glass, *Furnaces, *Corning Glass Works.

Available from the National Technical Information Service, Springfield, Va. 22161

PRICE CODE: PC A14/MF A01

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This report has been reviewed by the Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory - Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

This report contains results of studies and laboratory tests for a system to fill hot agglomerated glass batch materials into a melting furnace and to use furnace waste heat to preheat and prereact the batch agglomerates. The purpose of this study was to develop concepts, prove the feasibility of the concepts, establish cost estimates for pilot plant and production facilities, and establish expected energy, pollution, and economic benefits. This report should be of value to manufacturers of glass and glass ceramic materials.

For further information on the subject, the Energy Pollution Control Division should be contacted.

David G. Stephan
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ABSTRACT

In 1963, when energy was plentiful and relatively cheap, CORNING justified the installation of a waste heat boiler on one glass furnace. Even with escalating energy costs, a second installation has never been made. The key reason for this is that unless there is a stable, year-round use for stack waste heat, economic justification for installing a heat salvaging device is unattractive.

Ten years of no success in looking for easy answers to this energy problem suggested that a more fundamental approach might be more profitable. Five years ago an energy study produced the conclusion that preheating batch with furnace stack waste heat made more sense than any other option. The potential for faster glass melting would compound the energy savings, and in the energy transfer process, batch material normally lost from the stack might be captured.

In early 1975, while CORNING was investigating range costs of batch consolidating and preheating equipment, EPA expressed a very strong mutual interest in the development of this technology. The project was formally initiated with the signing of a contract between the Environmental Protection Agency and Corning Glass Works with an effective date of August 15, 1977. It is a jointly funded project with EPA providing 59 percent, DOE providing 33 percent, and CGW providing 8 percent of the program funding. This does not include the R&D facilities made available by CGW for the program. This report was submitted in fulfillment of contract number 68-02-2640 by CORNING Glass Works under the sponsorship of the U. S. Enviromental Protection Agency. This report covers the period from August 15, 1977 to November 1, 1978.

This project was initiated to demonstrate the feasibility of the glass batch preheating concept and to provide preliminary economic data on full-scale implementation of the concept.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BCL	Batelle Columbus Laboratory
Btu	British thermal unit
Btu/hr	Btu per hour
Btu/lb	Btu per pound
Btu/lb/°F	Btu per pound per degree F
Btu/ton	Btu per ton
cm	centimeter
CGW	Corning Glass Works
m^3/hr	cubic meter per hour
°C	degree Celsius
°C/hr	degree Celsius per hour
°F	degree Farenheit
DOE	Department of Energy
$/Btu	dollars per Btu
$/J	dollars per joule
$/kg	dollars per kilogram
$/lb	dollars per pound
$/ton	dollars per ton
EPA	Environmental Protection Agency
ft/sec	feet per second
FMC	FMC Corporation
ft	foot
ft/hr	foot per hour
GPI	Glass Packaging Institute
gm	gram
g/cc	gram per cubic centimeter
H.P.	horsepower
in	inch
in/sec	inch per second
J	joules
J/hr	joules per hour
K/hr-°C-m	joules per hour, degree C, meter
J/kg	joules per kilogram
J/kg/°C	joules per kilogram per degree C
J/yr	joules per year
kg	kilogram
kg/m	kilogram per cubic meter
kg/day	kilogram per day
kg/hr	kilogram per hour
kg/min	kilogram per minute

kg/sec	kilogram per second
kg/yr	kilogram per year
kPa	kilopascal
KW	kilowatt
KWH	kilowatt hour
KWH/hr	kilowatt hour per hour
m	meter
m/sec	meter per second
N	newton
PPM	parts per million
Pa	pascals
PGS	Pittsburgh Glass Sand
lb/hr	pounds per hour
lb/sec	pounds per second
rpm	revolution per minute
m^2	square meter
TGA	thermogravimetric analysis
TPD	tons per day
2-D	two dimension

SYMBOLS

Al_2O_3	aluminum oxide
A	bed cross-sectional area
L	bed height
B_2O_3	boron oxide
CaO	calcium oxide
CO_2	carbon dioxide
f	coefficient of friction
DS	Dravo series
T_{go}	exit gas temperature
T_{po}	exit pellet temperature
Fe_2O_3	ferric oxide
k	filter empirical constant
ρ	gas density
Q_{gas}	gas heat loss
M_g	gas mass flow rate
C_{pg}	gas specific heat
T_g	gas temperature
K_g	gas thermal conductivity
V_g	gas velocity
g	gravitational constant
R	individual sphere radius
T_{gi}	inlet gas temperature
T_{pi}	inlet pellet temperature
E_R	interception
P_D	jet pump discharge pressure
V_D	jet pump discharge velocity
W_s	jet pump, induced gas flow rate
W_j	jet pump jet air flow rate
P_j	jet pump nozzle pressure

V_j	jet pump nozzle velocity
Z	jet pump ratio of total flow to jet flow
P_t	jet pump throat pressure
V_t	jet pump throat velocity
W_t	jet pump, total flow rate
PbO	lead oxide
MgO	magnesium oxide
MS	Mars series
L_n	natural logarithm
NO_2	nitrogen oxide
Nu	Nusselt number
E	overall filter efficiency
L	packed bed thickness
β	packing density for spherical collectors
D	pellet diameter
Q_{pellet}	pellet heat gain
M_p	pellet mass flow rate
P_p	pellet porosity
C_{pp}	pellet specific heat
T_p	pellet temperature
%	percent
lbs	pounds
Pr	Prandtl number
H_L	pressure drop
Re	Reynolds number
S_iO_2	silicon dioxide
E_D	single sphere collection by diffusion
E_I	single sphere collection by inertia
E_G	single sphere collection by settling
$E_{\beta i}$	single sphere collection efficiency
Na_2O	soda
Na_2SO_4	sodium sulfate
K	specific heat of pellets to gases
SO_2	sulfur dioxide
SO_3	sulfur trioxide
Q_{loss}	system heat loss
B	transfer coefficient and cross-sectional area to the pellet mass flow rate and specific heat
μ	viscosity
h_v	volumetric heat transfer coefficient

SI CONVERSION FACTORS

To Convert From	To	Multiply By
Atmosphere (Atm)	Pascals (Pa)	1.013×10^{5}
Btu	Joule (J)	1.055×10^{3}
Erg	Joule (J)	10^{-7}
Foot (ft)	Meter (m)	3.048×10^{-1}
Foot^3 (ft^3)	Meter^3 (m^3)	2.832×10^{-2}
Inch (in)	Centimeter (cm)	2.540
Inch^2 (in^2)	Centimeter^2 (cm^2)	6.452
Kilogram force (kg)	Newtons (N)	9.807
Pound force (lb)	Newtons (N)	4.448
Pound mass (lb)	Kilogram mass (kg)	4.536×10^{-1}
Pounds per sq. in.	Pascals (Pa)	6.895×10^{3}
Standard Cubic Feet per hour	Cubic meters per hour	2.832×10^{-2}
Ton mass (short)	Kilograms mass (kg)	9.072×10^{2}

ACKNOWLEDGEMENTS

This research study included efforts from many individuals at Corning Glass Works. Major contributors were Mr. Richard C. Bauer, Mr. Gordon E. Burke, Mr. Robert B. Brown, Mr. Charles F. Canedy, Mr. David E. Koenig, Mr. Richard K. Peelle, and Dr. Paul F. Spremulli.

The Battelle Columbus Laboratories were subcontracted to participate in the laboratory and bench scale testing. Dr. J. Richard Schorr, Mr. Patrick M. Stephan, and Mr. E. D. Spinosa were major contributors.

The Midland Ross Corporation was subcontracted to participate in the concepts and engineering for the pilot plant drying and preheating. Mr. Morris Hakim, Mr. James Lyons, Mr. Frank Rinker, and Mr. Tom W. Schultz were major contributors.

The Thatcher Glass Manufacturing Company was subcontracted to participate in the engineering for the pilot plant hot transfer equipment and to conduct full scale flow control model tests. Mr. Gordon Hayes, Mr. Al Service, Dr. George Simmons, Mr. Thomas Mike, and Mr. Wayne Wallding were major contributors.

SECTION 1

INTRODUCTION

The Environmental Protection Agency contracted with Corning Glass Works for the development of a glass batch pretreatment process which would abate emissions and reduce energy usage in the melting furnace. The project is funded by the Environmental Protection Agency, the Department of Energy, and the Corning Glass Works.

The contract consists of two phases of work. Phase I, now completed and reported in this document, was a laboratory phase to supply the information needed to design a pilot plant system, and based on this design, to estimate the energy, pollution, and economic advantages of the program.

Phase II will consist of constructing and operating a batch preheating pilot plant test facility to confirm the bench scale test results and to provide the necessary design and operating information for a full scale production facility. The Phase II results will also be used to update the energy, pollution, and economic advantages of the process.

This report is submitted in fulfillment of the Phase I portion of Contract #68-02-2640 by Corning Glass Works under the sponsorship of the U. S. Environmental Protection Agency. The report covers the period from August 15, 1977 to November 1, 1978.

Phase I consisted of eight tasks and was primarily concerned with soda-lime glass batch since over 75 percent of the glass produced in the United States is of this composition. A limited amount of work was performed with borosilicate glass batch. These tasks are described below:

Task 1 - Information Analysis

An information and patent search was completed to document available literature concerning glass batch agglomeration and preheating.

Task 2 - Material Selection

Batch materials were investigated and selected to conform with present glass making practices, taking into account geographic locations and tonnages.

Task 3 - Consolidation

The process of pelletizing was characterized in terms of optimum materials, water content, type of equipment and equipment operations. Pellets and briquettes were made from soda-lime and borosilicate glass batches.

Task 4 - Drying and Preheating

A laboratory static bed preheater was constructed and operated to test the drying and heating of soda-lime glass batch pellets. Requirements for a production system were developed, and dried and preheated soda-lime glass batch pellets were supplied for subsequent tasks.

Task 5 - Pollutant Capture

The preheater was operated to determine the capture of sulfur dioxide (SO_2) and sodium sulfate (Na_2SO_4) particulates by a static bed of soda-lime glass batch pellets at 800°C. Typical flow rates and pollutant concentrations from a production glass melting furnace waste heat system were simulated. Preheated and partially prereacted pellets were supplied for analysis and melting studies.

Task 6 - Hot Transfer

The handling, flow, and sticking behavior of pellets were studied. Full scale testing was conducted feeding loose batch and cold pellets through a batch charger and a simulated furnace backwall.

Task 7 - Melting Studies

Comparative quality evaluations were made of crucible melts of preheated pellets, dried pellets, and various loose batch formulations.

Task 8 - Process Design Manual

A technology potential was completed, based on expected benefits for energy, pollution, and economics and information was developed to establish specifications and costs for a pilot plant system in Phase II.

SECTION 2

CONCLUSIONS

The conclusions derived from the Phase I studies are based on detailed experimental results on each aspect of the glass batch preheating technology. They include studies made on raw material acquisition and handling, chemical and physical properties of glass batch and batch materials, batch melting properties and glass melts quality. The following conclusions are based on the results of these experiments and studies.

RAW MATERIALS

Soda-lime glass batch materials can be pelletized and preheated prior to the introduction into a melting furnace. Although, minor changes in batch composition will be necessary, studies have shown that the raw materials required to produce pelletized batch are commercially available. The additional cost of the materials will be offset by the savings derived from improved furnace output. Studies of preheated pellets made from these batch materials have also shown that there should be an increase in glass productivity without a sacrifice in glass quality.

CONSOLIDATION

Both briquetting and pelletizing are viable methods of consolidating (agglomerating) soda-lime glass batch. Neither method is clearly superior to the other.

DRYING

Drying temperatures and rates for batch pellets were investigated to determine the importance of pellet strength and integrity. Since pellets when first formed are wet and weak, partial drying will be required for pellets to survive further handling.

PREHEATING

Soda-lime glass batch pellets preheated to 800°C were judged to have strengths satisfactory for feeding glass melting furnaces. No pellet sticking problem is anticipated at that temperature. From the static bed preheater experiments, relationships were developed for designing the pilot plant preheater. This work confirmed Columbia Gas pilot plant design equations for preheated batch.

PRE-REACTION

Pre-reaction of preheated pellets was investigated using a thermogravimetric analyzer. Pre-reaction is considered important because it means that the actual melting process will begin with some gaseous reaction products escaping before the materials are introduced in the melting furnace. Less gas introduced with the pre-reacted pellets requires less gas to be fined or removed from the molten glass bath, and hence melting rates may be increased or melting temperatures may be decreased. Studies showed that pre-reaction occurring below 600°C was insignificant, but that half of the possible pre-reaction occurred at 800°C.

POLLUTANT CAPTURE

Using a static bed preheater, studies indicated that 800°C soda-lime glass batch pellets can capture from 75-85 percent of the SO_2 in a gas stream flowing at 0.43 m/sec. (17 in./sec.) through the bed.

HOT TRANSFER

The static bed studies indicated that at least 32 percent of the Na_2SO_4 particulate matter in the gas stream can be captured, based on particulate in the 10 micron range.

MELTING STUDIES

The combined effect of a 50°C reduction in melting temperature and the associated 15 percent reduction in fuel results in an overall 65 percent reduction in expected NO_x emissions.

PILOT PLANT DESIGN STUDY

The average regenerative, soda-lime furnace stack, gas temperature is not high enough to preheat pellets to 800°C, although the energy lost through unefficiences is sufficient to do so. However, there are means to modify existing furnaces to achieve the desired temperature, while new furnaces can be specifically constructed to achieve the desired 800°C temperature. The pilot plant design will utilize a direct-fired furnace capable of achieving 800°C without modifications. Use of this type of furnace will not negate the results of the pilot study to verify the viability of the technology.

ENERGY AND COST SAVINGS

Energy savings are projected to be 8.5×10^{15} joules/year (1.4×10^{6} barrels of oil equivalent) if 35 percent of the soda lime container furnaces utilized this technology.

SECTION 3

RECOMMENDATIONS

The completion of the Phase I portion of the program has resulted in the identification of additional background requirements to the basic program. However, the results do indicate that the concept is both feasible and viable and that the final demonstration should be undertaken. Therefore, based on the Phase I results the following program actions are recommended:

1. The pilot plant, Phase II, should be pursued to confirm the pollution, energy, and cost savings benefits indicated and projected in Phase I and define and identify the operating characteristics of a production system. Furthermore, this demonstration will decrease costs and risks in developing a full-scale production application. Development of this concept will involve a major investment of capital. This magnitude of R&D investment is typically not possible in the glass industry which usually operates on a relatively low profit margin. Thus, this program would remove a significant part of the capital risks associated with R&D effort and would permit proceeding to the full-scale system with a minimum of risk.

2. Pelletized batch is the recommended method for batch agglomeration, however, additional studies could be conducted to verify the advantages of this procedure.

3. Prior to initiation of the demonstration, packed bed studies utilizing pelletized glass batch should be run to predict the particulate capture efficiency of a packed bed preheater. These studies should be conducted using actual operating regenerative furnace exhaust emissions.

SECTION 4

TECHNOLOGY DEVELOPMENT

Historically, the glass melting process has been considered as starting with the batch filling machine. The batch preheating program assumes that the melting process starts with the selection, consolidation, and preheating of the batch materials. It would be wrong to think, however, that this process cannot be adapted to present furnace design and operation to achieve the value of this concept.

The objectives of this research and demonstration program are to develop and demonstrate the feasibility of the glass batch preheating concept as an energy conservation and pollution reduction method. Each aspect of the glass manufacturing process has been evaluated to determine basic process and design parameters for the pilot plant and eventually for a full-scale production plant.

The laboratory research to develop the process parameters for this program was conducted at the Battelle Columbus Laboratories, Columbus, Ohio, and at the Corning Glass Works laboratory facilities in Corning, New York. The research conducted consisted of studies of batch formulation, melting, pelletizing, pollutant capture, and process and equipment concepts.

INFORMATION ANALYSIS

Considerable information was accumulated over the past several years by Battelle, Corning Glass, and others in the areas of pelletizing, drying, and preheating of glass batch. This information formed the base for the laboratory and bench scale testing.

A detailed review and analysis of available information pertinent to this program were completed. It was shown previously that considerable information of pertinent value exists. This information is compiled and analyzed in Appendix A. The information lies primarily in the areas of pelletization, drying, and preheating although pertinent information is also known to be available in the areas of materials selection, pollution control, hot transfer, and melting. It should be noted that much of the pertinent information is not publicly available, but was developed by Dr. J. R. Schorr, while he was at Columbia Gas.

The information is from published and unpublished literature, from Corning Glass Works, and from materials and equipment suppliers who have conducted related studies. Also, a survey was made of the melters, raw materials, compositions, locations, tonnages, cullet usages, and other aspects of the U.S. soda-lime glass industry. This was done so that the information derived during the project would be useable by the largest segment of the glass industry.

The information compiled was used as the basis for finalizing the detailed test program for the completion of the baseline technology needed for testing of the concepts at the pilot plant preheating and melting demonstration.

COMPOSITION AND RAW MATERIALS SELECTION

Composition and Raw Materials

The soda-lime glass compositions selected for study were based on analyses which were representative of the more typical compositions in use by the glass container and flat glass industries. The borosilicate composition under consideration was provided by Corning Glass Works. The major emphasis throughout the study was on the soda-lime container glass composition, since, according to the Glass Industry Review in Appendix A, the largest amount of glass produced in the United States is for glass containers. To assist Corning Glass Works in selecting and verifying the acceptance of the proposed glass composition, representatives of various industrial companies were consulted. Although the glass compositions naturally vary according to company, location, raw material availability, and other factors, the fundamental concepts for consolidation and preheating of glass batch derived during this project would apply to most glass compositions and manufacturing processes.

Soda-Lime Glass--

A typical clear soda-lime glass container composition, the starting composition used in this project, and the composition of the batch used in the pelletizing studies are shown in Table 1.

TABLE 1. SODA-LIME CONTAINER GLASS COMPOSITIONS

% Oxides	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3
Industry survey	72.75	14.6	-	10.6	-	2.0	0.05
Pelletizing batch	73.5	13.0	0.4	8.8	2.3	2.0	0.04

The calcium and magnesium oxides were the only oxides to vary significantly from those in the typical industry composition, because burned dolomite was used most extensively as a binder for the pelletized glass batch. Due to forming considerations, the industry trend in recent years has been to reduce the MgO content in container compositions. If MgO is undesirable in a manufacturers composition, burned high calcium limestone can be used as a binder replacing burned dolomitic limestone. Typical batch compositions of raw materials used in soda-lime glasses can be found in the Soda-Lime Glass Industry Review in Appendix A. Throughout all testing, the oxide composition of the batch was held constant with the exception of MgO and CaO. While the total MgO plus CaO was held constant, the ratio varied depending on the amount and type of binder used.

Although no specific flat glass batches were pelletized and preheated, the experimental results indicate their feasibility. These batches would be particularly well suited for pelletizing because of their high MgO content which would allow the use of a sufficient amount of burned dolomite as a binder. Typical soda-lime flat glass and batch compositions are given in the Soda-Lime Glass Industry Review in Appendix A.

Borosilicate Glass--

The borosilicate glass composition used in this study was that of a Corning Glass Works ovenware product. This glass composition is shown in Table 2, while the raw materials selections are discussed in more detail in a later section.

TABLE 2. BOROSILICATE GLASS COMPOSITION

Oxide	SiO_2	Na_2O	B_2O_3	Al_2O_3	Fe_2O_3
Percent by Weight	79.69	4.27	13.80	2.24	0.02

Raw Materials Selection For Soda-Lime Glasses

The raw materials used in this project were, for the most part, based on their use in various manufacturing facilities. Primary consideration in the selection of these materials was their availability, cost, reliability of supply, and representation of raw materials typically used in the container glass industry.

As research progressed on the pelletizability and pellet strength for different combinations and size distributions of raw materials, the combination of raw materials which exhibited optimum pelletizing and strength characteristics was chosen for further evaluation. The raw materials used for the soda-lime compositions and their typical chemical analyses are shown in Appendix B. Particle size distributions for these raw materials are also presented in this table.

A basic premise of the Columbia Gas pelletizing program as discussed in Appendix A, was that all container glass batches would need to be ground fine enough to obtain pellet strengths sufficient for a preheating system. An objective of this program was to select raw materials for pelletizing which were commercially available and which could be used to obtain sufficient pellet strengths, while minimizing cost penalties associated with the use of finer raw materials and binders which were not typically used in commercial batches. These selections are discussed further in the following sections.

Sands--

As shown in Appendix B, several types of sands were studied for their pelletizing characteristics in glass batches. The PGS Berkeley No. 1 dry sand was the only 20 x 140 mesh sand studied since it is typical of sands used throughout most of the soda-lime glass industry. The major variations in silica sources are in the alumina (Al_2O_3) and iron oxide (Fe_2O_3) contents of the sands. Feldspathic sands with higher alumina contents are used in some parts of the country, while some compositions (amber glass for example) require greater amounts of Fe_2O_3.

The PGS Berkeley 200 mesh Supersil sand was added to obtain preheated pellet strength. The Columbia Gas studies, Appendix A, indicated that fine silica in the batch was necessary to obtain sufficient preheated pellet strength. The Supersil sand is typical of ground silica readily available to most of the glass industry.

Although not available on a continuing basis, several other PGS sands were investigated for their pelletizing properties to determine the influence of variations in grain shapes and particle size distributions.

The PGS Berkeley Fine Dry Special Sand is theoretically desirable for pelletizing since it contains nearly 30 percent minus 200 mesh particles and only a small fraction of plus 50 mesh particles. This type of product from most deposits, however, is a screened byproduct and is not available in the large tonnages required by the glass container industry.

An alternate to adding coarse and fine sands separately to the glass batch for pelletizing would be to combine these fractions into one product at the sand producer's location. Two experimental sands were made by scalping the sand at 40 or 50 mesh, grinding the oversize, then adding the oversize back to the scalped product. This resulted in a more nearly continuous distribution of particle sizes in the sand than could be obtained when adding a 20 x 140 mesh sand and a minus 200 mesh sand to the glass batch. These types of products are not available currently on a commercial basis, since sufficient demand would be necessary to make a changeover in the sand producers' operations from the traditional glass grade sands to experimental sands economically feasible.

A PGS sand produced at Mill Creek, Oklahoma, currently supplied to the glass industry, was used in some of the initial pelletizing batches. This was a 50 x 200 mesh sand, which seemed to be particularly suited for use in a pelletizing batch. The sand grains were rounded as opposed to the sub-angular shaped grains found in the sands from the Berkeley Springs, West Virginia, deposits.

Alumina Sources--

Three grades of nepheline syenite were used in the initial characterization studies. The minus 30 mesh grade is used most commonly in the glass industry while a 40 mesh grade is used when higher pull rates or faster melting is desired. The minus 200 mesh grade was used to study the effect of finely ground nepheline syenite on green and fired pellet properties. Nepheline syenite is manufactured by two companies near Nephton, Ontario, Canada, and is, therefore, used most extensively in the northeast United States.

Feldspars, like nepheline syenite, are used to satisfy the alumina requirement in many glass compositions. Feldspathic sands are produced in some parts of the country where nepheline syenite and pure feldspars are not available on a economically competitive basis. All of these materials could be used in pelletized glass batches when the proper combination of binders and particle size distributions exists for all of the other raw materials in the batches.

Soda Ash--

The soda requirement for the pelletized glass batches was supplied by Stauffer Chemicals' Dense Western soda ash produced by the natural trona process at Green River, Wyoming. This soda ash has a rounded grain shape. Other companies such as Allied Chemical, FMC, and Texasgulf supply similar products from the Green River deposit. Very few Solvay-process soda ash plants remain in the United States, although this type of soda ash would also be suitable for pelletizing. FMC manufactures another type of soda ash at Green River which has an acicular grain shape with a size distribution similar to the regular grades of soda ash.

Limestone--

Several lime sources were used in this program. The limestone originally used for the pelletizing experiments was a standard glass-grade product produced by the Warner Company in Bellefonte, Pennsylvania. Due to the very coarse nature of the product (16 x 100 mesh), several pelletizing and pellet preheating problems were encountered with its use. Trials were made by scalping, in the laboratory, product greater than 50 mesh screen, and then ball milling the oversize fraction and adding it back to the undersized fraction. This product was used successfully in several trial experiments to evaluate the influence of the coarser size fraction. Since it was not available in greater quantities for the larger scale pelletizing experiments, a switch was made to a finer limestone from the same geographical area.

The National Gypsum Company manufactures a 40 x 200 mesh limestone at York, Pennsylvania, which was used to replace the Warner limestone. Although it is not being used by any glass manufacturer, this type of limestone is well suited for use in a pelletized glass batch due to its particle size distribution, which contains a minimum of very coarse or very fine particles. This grade of limestone is not widely available and would require sufficient demand before larger quantities would become available from the major limestone producers. Aragonite is another product which is becoming more widely available in the Eastern United States, and since it has a finer particle size distribution than regular glass grade limestones, it would seem better qualified for use in pelletized glass batches. Experiments were not conducted, however, to evaluate the suitability of aragonite or any other limestones for the pelletizing and preheating process.

A pulverized, minus 200 mesh limestone product from the Warner Company was also used to determine its influence on pellet properties.

Binders--

Burned dolomitic limestone was selected as a binder for the glass batch pellets because of its availability and cost in comparison to other commonly used binders such as caustic soda, bentonite, or sodium silicate. The major glass-grade dolomite deposits are located in Northwestern Ohio, Eastern Pennsylvania, and Central California. The 40 mesh burned dolomite provided by the National Lime and Stone Company in Carey, Ohio, was used predominately throughout the laboratory program. Some experiments were also conducted using a 100 mesh burned dolomite from the Ohio Lime Company at Woodville, Ohio.

As mentioned previously, the glass container industry compositions in recent years have contained less MgO. For this reason, exploratory experiments were conducted with several alternate binders used in experimental glass batches. These included two types of burned high calcium lime and a hydrated high calcium lime. These materials are also more widely available and would be less costly than caustic soda or sodium silicate.

Fining Package--

Sodium sulphate, or salt cake, and carbocite were used as a fining package in the container glass compositions. Since these materials contribute less than one percent by weight to the normal glass batch, they have little influence on the pelletizing properties of the batch. Also, one objective of the pelletizing and preheating of glass batch is to use waste heat from the glass furnace to preheat the pellets, the volatile constituents of the batch will, to some extent, be captured in the bed of pellets. In container glass compositions, a major portion of the volatile fraction consists of sodium sulphate particles and SO_2 gas. In actual practice some balance of batched and recycled sulphates must be determined. Also, the carbocite, an anthracite coal, would not be expected to completely remain in pellets heated to 800°C but will be evolved as CO_2 to an extent which must be determined.

Other types of fining agents and batch additives such as niter, gypsum, arsenic, selenium, and others would again not be expected to influence pelletizing properties since they constitute a small fraction of the batch, although they could influence the type and amount of the solid-state reactions in the pellets during preheating.

Other Additives--

Other batch additives could include the use of surfactants to promote particle wetting and allow a reduction in the pelletizing moisture requirement. Aerosol OT is a surfactant manufactured by American Cyanimid which was used to explore the effect of a surfactant on the pelletizing of a glass batch. Surfactants are available in liquid and powdered form, and may be added to the batch during mixing or can be sprayed on while pelletizing. Although not used in this project, certain types of flocculants could possibly enhance the pelletizability of certain glass batches. The use of halide compounds as batch additives to promote loose batch reactions during preheating has also been proposed in British patent number 1,172,318 issued to Compagnie de St. Gobain.

Recommended Starting Batch For Phase II--

As a result of the bench scale testing and materials evaluation, MS-11 (Appendix A) was selected as the recommended batch to start the testing in the pilot plant. This batch composition and its oxide composition are shown in Table 3. This oxide composition is the same composition originally selected (Table 1) with the exception of the ratio of CaO to MgO.

TABLE 3. RECOMMENDED PILOT PLANT BATCH COMPOSITION

Raw Material	Percent by Weight
PGS Berkeley No. 1 Dry Sand	38.7
200 mesh Supersil	20.8
Limestone	11.7
Burned dolomite	3.3
Neph. Syenite	7.2
Soda ash	17.7
Salt cake	0.5
Carbocite	0.1
Total	100.00

RECOMMENDED PILOT PLANT GLASS COMPOSITION

Oxide	Percent by Weight
SiO_2	73.5
Al_2O_3	2.0
CaO	9.4
MgO	1.7
Na_2O	13.0
K_2O	0.4
Total	100.00

Raw Material Selection for the Borosilicate Glass

Boron source selection was reduced to the more common products: technical grade, granular, boric acid; "5 mol borax" (sodium tetraborate, pentahydrate); and anhydrous borax, 30 mesh, granular. These compounds were selected due to their projected availablitiy and lower cost.

The large relative amount of bound water could cause problems in preheating, but the anhydrous versions of these products are nearly impossible to wet. The addition of water yields difficult time vs. hydration phenomena which would be serious limitations in the pelletizing steps, if the anhydrous products are used.

The sand studied was the (Mill Creek) Oklahoma #1 Dry.

The alumina source was C-11 product from Kaiser chemicals. Equivalent products are Reynolds (RC-23) and Alcoa (A-1).

The use of soda ash was optional

The fining agent was sodium chloride, a typical fine product with low lead contamination. (Watkins Salt Company product AN-35).

Segregation Study on Selected Container Soda-Lime Batch

A sample of the MS-11 batch was sent to Richard L. Lehman and Paul R. Kessler at the Industrial Chemical Group of FMC in Princeton, N.J. They tested the material with a procedure they have developed to measure the segregation potential for batch.

Two one-hundred gram splits were taken from the MS-11 batch and each tested through a segregation sandwich. This device is a thin plexiglas sandwich which represents a section of a storage bin. The inclined surface inside the section induces material flow similar to that observed in full scale bins. The degree of segregation is quantitatively determined by measuring the material size variation at nine positions across the bin section. The degree of segregation is proportional to the coefficient of variation measured.

The segregation sandwich test confirms that the degree of demixing is very low. For a standard glass batch, the expected segregation level is approximately 70% while the MS-11 batch yielded only a 2.8% variation of coarse fines throughout the sample. From these data it is apparant that virtually no segregation occurs in the MS-11 batch due to its very cohesive nature. Therefore, further design of bins and conveyance devices for this material can proceed with little regard for avoiding segregation.

CONSOLIDATION

The current technology for preheating glass batch requires the batch to be in a consolidated form. Several methods of consolidation are employed by different industries (1). Pelletizing and briquetting are preferred for glass batch from a cost and processing standpoint.

Since the main objective of this project is to prove the energy conservation and pollution abatement benefits of preheating glass batch, the form of consolidated batch can be treated primarily as a means by which the glass batch is processed for use in conventional preheating furnaces. Several patents and methods exist for preheating loose glass batch, and these were described in the Literature Survey abstracts and patents in Appendix A.

Selection of Consolidation Method

Pelletizing vs. Briquetting--

Several references that review briquetting and pelletizing are available in the literature; however, no comprehensive studies have been made to compare briquetting and pelletizing of glass batch under the same test conditions, that is, similar compositions and raw materials, similar test methods, and other similar factors. Unfortunately, such information, needed for a proper comparison of the two consolidation methods, has either not been derived or is not available in the general literature.

In order to fully evaluate the differences between the pelletizing and briquetting processes, information was gathered from several pelletizer and briquetter manufacturers, and Corning Glass Works and Battelle representatives attended a short course entitled "Briquetting and Pelletizing" at The Center for Professional Advancement, East Brunswick, New Jersey. Some information was also available from previous work done at Columbia Gas and at Corning Glass Works. The following is a synopsis of the information which guided the selection of pelletizing as the method of consolidation in this project.

Comparing the cost of briquetting and pelletizing gives neither a clear advantage. The capital cost of a briquetting system is nearly twice that of a pelletizing system. However, batch cost is higher for pelletizing because of the substitution of fine sand (-200 mesh) for 35% of the coarser sand. Maintenance cost is higher for briquetting because of roll wear, with the roll wear cost information the largest unknown. Using $1.50 per ton for roll wear, neither method is significantly more economical; however, estimates of roll wear range from $0.45 to $4 per ton.

Most references indicate that pellets require 7 to 15 percent moisture while briquettes require 4 to 13 percent moisture. Lower moisture contents (7 to 11 percent) exist with deep pan pelletizers for a given composition. Pellets can have a tendency to decrepitate while drying if the drying temperature is too high for the given composition, presumably this would also be true for briquettes. A proper preheater design which includes a drying section would most likely eliminate this tendency. Briquettes also need to be dried, whether in a preheater or separate drier, but the costs of drying would be less since there is less moisture to remove. The need for a binder with briquetting of certain glass batches is not clear. Studies have been made with and without binders.

Because briquettes are denser than pellets, they have higher thermal conductivity. On the other hand, the shape of briquettes would contribute to channeling of the hot gases in a shaft preheater resulting in poor temperature distribution. In addition, there is no previous experience in preheating glass batch briquettes in a shaft preheater.

Since no complete studies have conclusively shown a real technical or economic advantage for either briquetted or pelletized batch, the pelletizing-preheating system was preferred because pelletizing will have potentially less downtime and fewer costs associated with maintenance. Possible advancements in briquetter design and roll wear could change this in the future, but evidence to date does not show briquetting to have any clear-cut advantages over pelletizing and, in fact, the reverse appears to be more likely.

Pelletizer Types--

Meetings were held in late September, 1977, with several pelletizer manufacturing representatives. Feeco International, the Mars Mineral Corporation, Eirich Machines, Ltd., and the Dravo Corporation (by film) were represented. Their pelletizers were discussed with emphasis on start-up and shut-down procedures, operational stability, pellet size uniformity, batch segregation, maintenance, and cost. Based on the discussions with these manufacturers, the deep pan pelletizer was chosen for use in this project.

The terms shallow, medium, and deep pan pelletizers refer to the ratio of rim height to diameter of the pelletizing discs. The rim height to diameter ratios for the shallow, medium, and deep pans are approximately 0.1-0.15, 0.2-0.4, and 0.5-0.8, respectively. A schematic showing the operation of a deep pan pelletizer is given in Figure 1.

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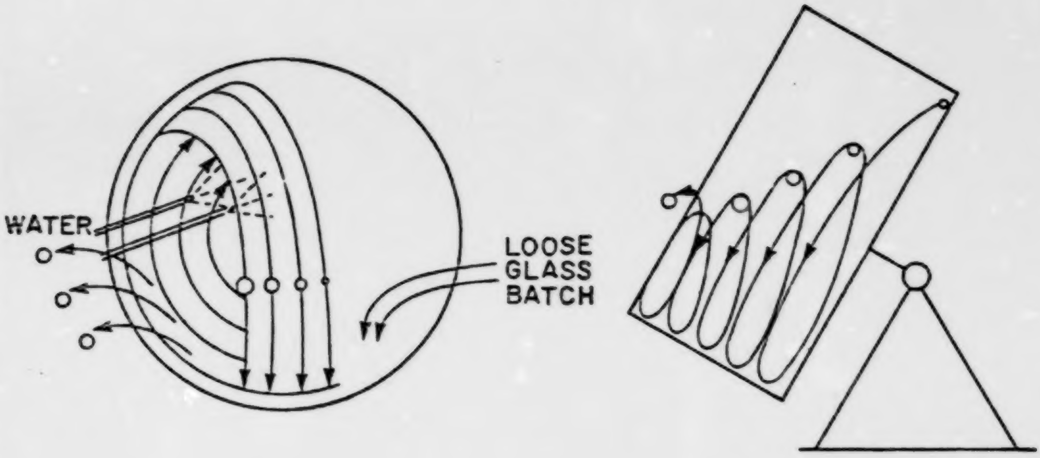

FRONT VIEW

SIDE VIEW

Figure 1. Schematic of pan pelletizing operation.

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Soda-Lime Glass Batch Pelletizing

Pelletizing Equipment--

The pelletizers used by Battelle included a Mars Minerals Series 20 agglomerator, which was used for pelletizing larger amounts of glass batches (320 kg/hr) and for extended tests, while small batch experiments were conducted on a modified 30 cm diameter Dravo pelletizer. The Mars pelletizer was fed by an auger into the rear of the pelletizer which was supplied with batch from a bin placed directly over the auger. The Dravo pelletizer was fed with batch in the initial experiments by a screw feeder, but due to stability problems it was subsequently fed by hand.

The Mars pelletizer has a diameter of 61 cm, with a rim height to diameter ratio of 0.77. The Dravo pelletizer has a diameter of 36 cm and was originally modified from a shallow pan to a scale model of the larger Mars pelletizer by welding a higher rim onto the existing rim. This higher rim was later cut into two sections so that the rim height to diameter ratio could be changed to lower values desired for some glass batches.

Water sprays were connected to the pelletizers such that one or two water sprays could be used with separate pressure regulators, valves, and flow meters. The water sprays were adjustable so any location in the pelletizers could be wetted, and the nozzle types used provided a solid, flat stream of water to the desired locations. In addition, a hot water tank was installed to provide warm water for some experiments.

The pan angles and rotational speeds were adjustable on both pelletizers, and the Mars pelletizer has an adjustable feed rate ranging from 135-540 kg/hr for glass batch. Figure 2 shows the two pelletizers.

Raw Material Variables--

To obtain pellets of uniform size and sufficient strength for processing, batch raw materials should be chosen that provide a wide particle size distribution with as few +50 mesh particles as possible and contain a binder to provide a continuous matrix throughout the pellets which binds the larger particles together. Selection of these materials was discussed earlier.

Binders are necessary in most consolidation processes to provide sufficient strength for further handling to the consolidated material. Binders can be classified into four types: matrix, film, chemical, and lubricant(2). Matrix type binders are continuous throughout an agglomerate and "fix" the particles in position. Film type binders may be solutions or dispersions. Chemical binders rely on reactions between particles in the agglomerate to provide strength, while lubricants function by

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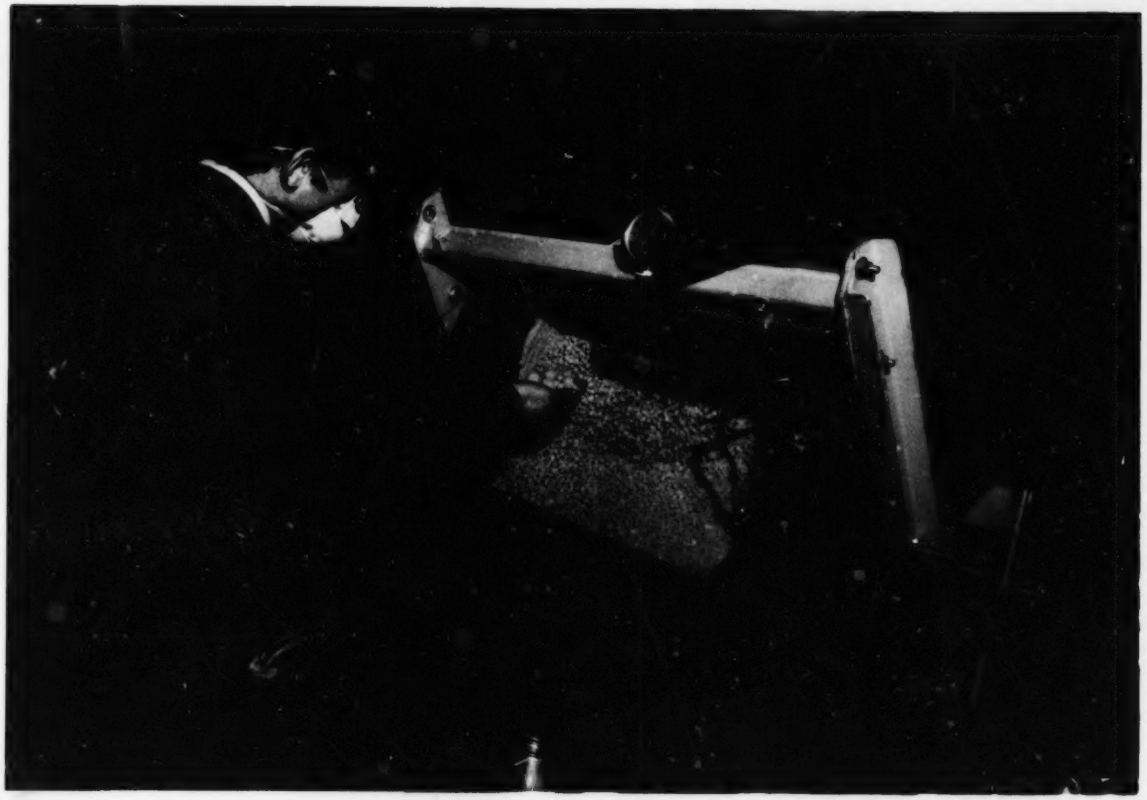

Mars Pelletizer

Figure 2. Pictures of pelletizers used in BCL experiments.

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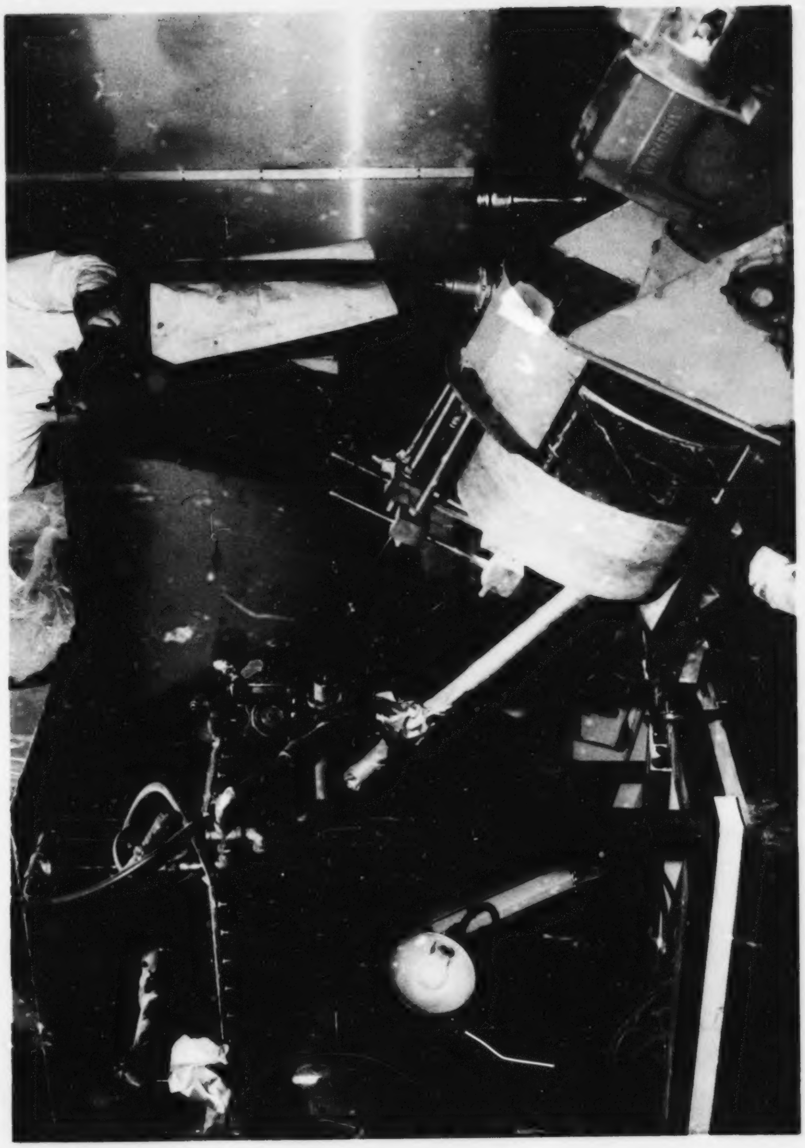

Figure 2. (Continued).

Dravo Pelletizer

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reducing the friction between particles. Many binders may exhibit several of these characteristics. Binders also generally fill the voids in agglomerates, thus increasing the density and lowering the porosity.

In soda-lime glass batch compositions, binders commonly used for pelletizing have been caustic soda, burned or hydrated limes, sodium silicate, clays, and portland cement. In other glass compositions such as borosilicates and lead glasses, additional binders may not be needed due to the reaction of some of the normal batch components with water added to the pelletizer.

Particle Size Distribution--Pelletizing of glass batch is different from most pelletizing applications since the feed material is comprised of many raw materials having different shapes, size distributions, and densities. Since pelletizing involves the consolidation of materials through a continuous particle packing and binding process, particle size distribution must be controlled to achieve the desired pellet properties. A general guideline for pelletizing the glass batch in a deep pan configuration has been to limit the +50 mesh fraction to a maximum of 20 percent and the minus 200 mesh fraction to a minimum of 20 percent. Variations in the amount or quality of the binder may require deviations from these guidelines. On the other hand for preheated pellet strength, the 200 mesh fraction of the batch must contain a considerable amount of silica to promote solid state reactions among the batch particles. Sieve analyses of several MS (Mars Series) batches are presented in Table 4.

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TABLE 4. SIEVE ANALYSIS OF MS BATCHES

Sieve no. (U.S. Standard)	Openings		Cummulative weight percent by weight retained on sieve									
	in	mm	MS-0	MS-1	MS-2	MS-3	MS-4	MS-5	MS-6	MS-7	MS-8	MS-11
20	0.0328	0.833	TR[a]	TR	TR	TR	TR	TR	TR	TR	TR	TR
45	0.0138	0.350	16.0	16.5	17.2	16.4	20.0	24.9	21.5	16.9	17.0	17.0
70	0.0082	0.208	49.0	48.2	52.0	48.4	56.0	63.9	56.0	43.0	46.9	52.0
100	0.0058	0.147	62.0	61.2	64.0	60.4	69.5	75.4	67.0	54.0	57.8	63.9
140	0.0041	0.104	-	71.3	74.0	-	-	-	76.9	71.3	66.8	72.1
200	0.0041	0.074	-	77.6	78.9	-	-	-	80.8	75.4	71.0	77.0
270	0.0021	0.053	97.0	98.5	97.9	97.3	98.4	98.9	98.3	99.4	98.3	96.7
Pan	-	-	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] TR = <0.1 percent.

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Mixed Batch Variability--Variability in the chemistry of mixed batch has always been a problem in the glass industry because of the number of handling steps between mixing and melting operations. Batch is often variable because of segregation in storage bins. One solution which has reduced this problem has been to wet the glass batch after or during mixing, causing the soda ash to partially dissolve and make the batch particles stick together. This is in itself, a form of agglomeration. Segregation has been worsened at times when pelletizing glass batch because of the wide difference in particle size distribution in the raw materials. Elimination of coarse particles is necessary to avoid this problem. A deep pan configuration reduces the opportunity for batch segregation in the pelletizer since the discharging pellets do not come into contact with loose batch.

Pelletized batch when made properly, has far less chance to segregate by the time it reaches the melter since the batch particles are all fixed in position and will melt faster because of the intimate contact between the quartz grains and fluxing materials.

Composition Differences--Soda-lime container glass batch requires the addition of a binder such as burned dolomite or caustic soda to acquire sufficient strength for further handling. As noted previously, other compositions contain raw materials which are natural binders, such as clays and borates.

Pelletizer Operating Variables--

Sufficient knowledge of pelletizing operational variables leads to more efficient processing with a minimum of generated waste. Although batch and equipment variables are often interrelated, the glass batch can not be changed as easily as adjustments can be made to the pelletizing equipment to maintain stability or uniformity of the pellet size distribution.

Start-up and Operating Procedures--Start-up of a pelletizer requires formation of seed pellets and uniform growth of pellets by constant material feed and water addition. Water (in excess of 12 percent) was added to form the initial seed pellets. This was followed by a gradual decrease in water addition to the desired moisture content allowing the formation of nucleation and growth regions in the pelletizer. The desired moisture content was determined by the pellet size distribution required, the amount of surface moisture allowed, and the strength exhibited by the pellets discharging from the pelletizer. Pellets with an excess or insufficient amount of moisture deformed or fractured during handling. After the pelletizer has stabilized, the pan angle and rotational speed was adjusted to obtain the desired pellet size distribution. If operational instability or particle segregation occurred, adjustments were made to correct the problem. These adjustments were found to be made easily to the pelletizer;

however, operational problems were experienced due to a coarse limestone (-16 mesh) in the batch. When the limestone was replaced by a much finer limestone (-40 mesh), pelletizing was found to be easier in both the Dravo and Mars pelletizers.

Pan Angle--A change in the pan angle of the pelletizer can effect the size distribution of the pellets. Shallow pan pelletizers are usually operated with pan angles varying from 40-45 degrees as measured from horizontal to the sides of the pan, as shown in Figure 3.

The Eirich pelletizer used in the Columbia Gas study (Appendix A.) was operated at a pan angle of 30 degrees. In Battelle's laboratory experiments, the small Dravo pelletizer was operated between 18 and 38 degrees to obtain nominal 1.3 cm diameter pellets from the wide range of batch compositions. The Mars pelletizer produced pellets of the desired size distribution when operated between 21 and 25 degrees, although once the angle was determined for a given batch composition and moisture addition, changes of one degree in the pan angle would cause a significant change in the size distribution of the pellets discharging from the unit. Trials with a shallow pan pelletizer with a diameter of 91 cm were run with a pan angle of 42 degrees. This same pelletizer with the rim height doubled was operated with the pan angle at 28 degrees. This change in pan angle was necessary to obtain the desired size distribution of pellets.

In general, increases in pan angle allowed a longer retention time, cause the pellets to grow larger, and may increase pellet strength. Lowering the pan angle decreased retention time, and resulted in a smaller particle size distribution and in a lower pellet strength.

Rotational Speed--As with the pan angle, the rotational speed of a pelletizer influenced the ultimate size distribution of the pellets, although it was not as significant as changing pan angle. The proper combination of pan angle and rotational speed produced observable pellet nucleation and growth regions in the pelletizer. With the increase in centrifugal force, caused by greater rotational speeds, batch and pellets were thrown against the rim of the pelletizer, which may contribute to instability and segregation. Lower than normal rotational speeds did not allow the nucleation and growth regions to form properly in a pelletizer. For the experimental batches made on the Dravo pelletizer, the linear speed of a point on the rim of the pan was maintained between 35-40 meters/min (rotational speed 30-35 rpm). The Mars pelletizer was operated with speeds ranging from 40-50 meters/min (rotational speed 20-25 rpm). Linear speed was calculated by measuring the distance traveled per unit length of time by a point on the outside rim of the pelletizer.

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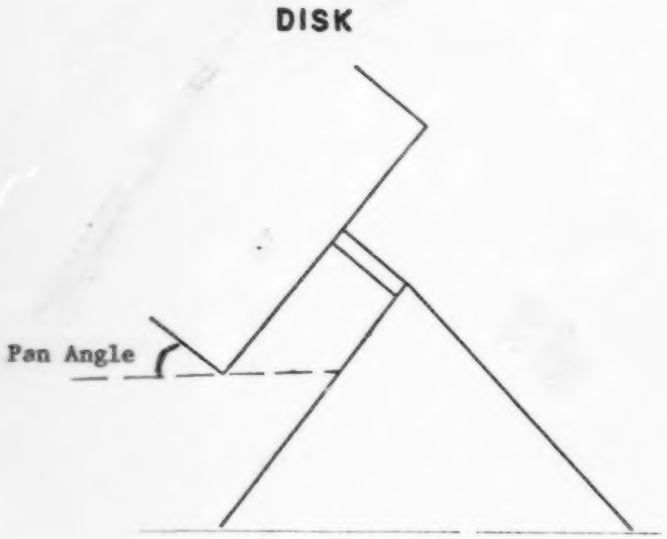

Figure 3. Pelletizer operating angle.

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Water Flow, Spray and Feed Location, and Temperature--Water addition in most pelletizing operations is the most critical parameter that must be controlled in order to maintain operational stability. Floyd and Engelleitner claim that input feed moisture should not vary by more than ±0.2 percent in an automatic operation and by no more than ±0.3 percent when an operator is controlling the unit (2). Results of glass batch work for this program has shown that variations in feed mositure as low as ±0.5 percent caused cycling of the size distribution of discharged pellets. Small changes in water addition were readily observable in the nucleation zone of the pelletizer where seed pellets change size rapidly. The percentage of feed moisture was calculated by dividing the weight of water added to a given weight of feed material in the pelletizer. Water addition was controlled using pressure regulators or metering regulators. Results indicated that a pelletizer will not achieve stability without some method of water flow regulation.

Several types of spray nozzles were utilized in the laboratory experiments. Those used most frequently with the best results were the flat spray types. The spray width influenced the shape, size, and impact of the water droplets, which in turn regulates the size of the seed pellets. Narrow sprays with larger droplets produced larger pellets, while wider and finer sprays may cause smaller pellets to form in the pelletizer. The influence of the spray nozzles varies with the size distribution of the feed material. The temperature of the water in laboratory pelletizing experiments was normally 15°C, while the temperature of the batches in the Mars pelletizer varied from 30° to 45°C due to the exothermic hydration reactions of the batch materials. An increase in water temperature to 55°C by hot water addition caused the batch temperature to increase by 4°-5°C, although only a slightly noticeable change in the pelletizability of the batches occurred. The literature discusses the importance of temperature in glass batches containing soda ash. It was reported that below 35.4°C more water is required by the batch due to the formation and stability of sodium carbonate heptahydrate (3). Above 35.4°C, sodium carbonate monohydrate is stable. Most of the heat generated when wetting the glass batch is due to the heat of hydration of the burned lime and soda ash.

Scraper location and materials--Scrapers, or plows, were used in the pelletizer to control the build-up of material on the bottom and rim of the pelletizer, as well as to direct the different pellet growth streams into separate paths. These scrapers were generally set to allow a small buildup of material in the pelletizer to aid the rolling and tumbling action of the pellets and feed material.

The scraper should be made of very hard materials which will not significantly contaminate the glass batch. Due to the abrasive nature of glass batch, very hard ceramic materials may be used to extend the life of the scrapers.

Pelletizer Stability--Pelletizer stability is a function of the degree of control over the pelletizing variables of water and feed material addition, as well as pan angle and rotational speed. Stability was found to be sensitive to changes in the water addition, which effect an instantaneous change in the size distribution of the pellets.

To determine the stability of a container glass batch in a large pelletizer, batch MS-11 was selected for a 3 hour trial in the Mars pelletizer. Table 5 shows that through most of the test, 90-100 percent of the pellets were between 1.0 cm and 1.9 cm (3/8-in to 3/4-in) diameter, which is an acceptable size distribution for use in a shaft preheater. Strength test results for dried and preheated pellet samples that were taken at regular intervals during the stability test are shown in Table 6. While somewhat variable, the strength results were judged to be adequate for the manufacture of pellets in the Phase II pilot plant studies.

The yield of acceptable pellets during the test was nearly 90% which is somewhat low because of an upset that occurred during the test. Controlled addition of feed material and pelletizing moisture allows continuous production of pellets with a minimum of operator supervision.

Pelletizer Capacities--The maximum capacity of a pelletizer is equal to the feed rate at which pellets of the minimum acceptable size and strength can be made. Larger pelletizers are generally operated within 50-100 percent of the maximum capacity. The Battelle Mars Series 20 pelletizer was operated at 25-50 percent of rated capacity with favorable results. Pelletizer manufacturers generally recommend laboratory trials on small units which can be scaled to establish capacities of larger units.

To stabilize a pelletizer the pan angle and rotational speed should be set to create the proper material flow patterns in the unit. The water content and spray locations should then be adjusted to obtain the desired size distribution of pellets.

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TABLE 5. SIZE DISTRIBUTION OF MS-11 PELLET SAMPLES TAKEN DURING STABILITY RUN OF APRIL 28, 1978

Time from start of sampling, min		Percentage of pellets between given diameters					
	Diameter, cm	0.6-1.0	1.0-1.3	1.3-1.6	1.6-1.9	J1.9	1.0-1.9
	Mesh size, in	1/4-3/8	3/8-1/2	1/2-5/8	5/8-3/4	J3/4	3/8-3/4
0		10.5	63.6	23.7	2.5	-	89.5
15		1.5	25.7	67.4	5.3	-	98.4
30		0.1	3.4	25.0	63.9	7.6	92.3
45		0.7	8.7	38.8	46.2	5.6	93.7
60		1.4	35.3	57.3	6.0	-	98.6
75		0.3	9.0	43.8	44.8	2.1	97.6
120		-	2.2	11.8	30.8	55.3	44.8
135		0.3	27.9	66.1	5.7	-	99.7
150		0.3	6.9	56.7	31.1	4.9	94.7

TABLE 6. STRENGTH TEST RESULTS FOR MS-11 PELLETS TAKEN DURING STABILITY RUN OF APRIL 28, 1978

Time of sample, min	0	15	30	45	60	75	120	150
Temperature, °C	200	200	200	200	200	200	200	200
Average crushing force, N	110.8	196.1	299.1	271.6	234.3	265.7	185.3	146.1
Standard deviation	13.7	47.0	51.9	28.4	42.1	30.4	45.1	28.4
Average strength, x10^{4} Pa	81	127	154	167	142	162	111	99

Time of sample, min	0	15	30	45	60	75	120	150
Temperature, °C	650	650	650	650	650	650	650	650
Average crushing force, N	19.6	29.4	35.3	29.4	30.4	36.2	29.4	23.5
Standard deviation	1.9	6.8	5.8	6.8	3.9	6.8	8.8	3.9
Average strength, x10^{4} Pa	12.7	15.6	21.5	70.6	18.6	21.5	15.6	12.7

TABLE 6. (Continued)

Time of sample, min	0	15	30	45	60	75	120	150
Temperature, °C	400	400	400	400	400	400	400	400
Average crushing force, N	58.6	89.2	122.5	102.9	109.8	112.7	90.2	59.8
Standard deviation	12.7	17.6	12.7	31.3	12.7	13.7	14.7	13.7
Average strength, $\times 10^4$ Pa	40.2	58.8	73.5	64.7	67.6	67.6	51.9	46.0

Time of sample, min	0	15	30	45	60	75	120	150
Temperature, °C	750	750	750	750	750	750	750	750
Average crushing force, N	65.7	111.4	95.1	95.1	100.0	96.1	82.3	105.9
Standard deviation	12.7	41.1	19.6	23.5	19.6	26.4	27.4	27.4
Average strength, $\times 10^4$ Pa	46.0	66.6	55.8	58.8	61.7	55.8	51.9	61.7

Pellet Properties--

Although the primary response to changes in compositions and test conditions was altered pellet strength, several other tests were conducted to characterize the raw materials and the glass batch pellets.

Description of special testing equipment--Sieve analyses of raw materials, batches, and pellets were performed using full height U.S. Standard Series sieves which were 20 cm in diameter. Compressive strength of pellets was determined with a Dietert Model 401 motorized compression strength tester. This apparatus is normally used to determine strength of sand core specimens, but was modified for pellets by installing special platens.

Pellet abrasion tests were conducted using a 20 cm diameter ball mill (with the balls removed) which contained a cylindrical steel insert with two lifter bars with a height of 1.3 cm.

A Harrop electric furnace normally used for high temperature creep tests was modified for hot load strength tests on small beds of pellets. An 8.7 cm diameter cylindrical alumina crucible was filled with a 12.7 cm column of pellets and a plug of castable refractory was used to distribute the column load evenly over the bed of pellets. A recorder capable of monitoring temperature, load, or deformation was connected. A load cell was used to calibrate the loading mechanism in the furnace, and a linear variable differential transformer (LVDT) equipped with a dial gauge detected any movement of the column. Temperatures inside the alumina crucible were monitored by placing a thermocouple through the sidewall of the crucible and into the middle of the column of pellets.

Test descriptions--Sieve tests of raw material samples and mixed batches were made by riffling samples down to 100 grams, the sample in a nest of sieves for ten minutes using a vibrating standard RO-TAP sieve shaker, and then weighing the amount of material retained by each sieve. A summary of the results are reported in Appendix B, Table B-3.

Free fall strength of pellets was determined by selecting 10 pellets at random from each test lot and dropping the pellets individually from a height of 46 cm onto a laboratory bench until the pellets fractured. The average number of drops sustained by the 10 pellets was reported as the drop test number.

Compressive strength was measured on the Dietert machine by selecting 10 pellets at random from the test lots which had been screened to 1.3-1.5 cm diameters. An average diameter was determined for the 10 pellets, then each pellet was placed between the platens on the testing apparatus. The motor was turned on, and the pellet was subjected to an increasing load until the pellet fractured. A traveling magnet stopped at the point on the scale where the pellet fractured. The scale reading was recorded and multiplied by a scale factor of pi (3.14) since the scale was calibrated for 2 inch diameter sand core specimens. The average strength of the 10 pellets was calculated as the pressure acting on a cross section through the center of the pellet and reported for each lot.

Abrasion loss was determined by tumbling 1000 grams of pellets in a jar mill at 52 revolutions per minute for 10 minutes. The pellets were then separated from the abraded material with a 10 mesh screen, and abrasion loss was reported as the percent passing through a 10 mesh screen. See Appendix B, Table B-9 for test results.

Hot strengths, per se, of individual pellets were not determined; however, results reported by Columbia Gas normally showed pellets to be stronger when hot than if they were allowed to cool before testing (Appendix A). Therefore, to determine the hot strength of pellet beds, tests were conducted in the Harrop electric furnace previously described. Some tests were conducted by placing the pellets in the furnace at the desired temperature, and then measuring deformation under an applied load. Other tests were conducted by measuring deformation under different loads as the pellets were taken from room temperature up to preheating temperatures. The pellets were then later observed for signs of fracture or deformation.

Individual pellet density was not determined on a continuing basis because of the difficulty of the test. Measurement was attempted by weighing individual pellets, dipping them in wax, weighing again, then measuring the volume of water displaced by the pellets in a graduated cylinder. In a second method, a basketfull of wax-coated pellets were suspended in kerosene to determine the apparent specific gravity. Values varied significantly but averaged nearly 2160 kg/m^3. Columbia Gas tests showed pellet density to vary inversely with weight loss up to preheating temperatures. Bulk density of pellets was determined by weighing pellets in a box of known volume. The bulk density of the selected batch pellets (MS-11) was 1150 kg/m^3.

Weight loss of pellets was determined by weighing several pellets from a test lot while still wet from pelletizing, placing these pellets in crucibles in a small electric oven for the desired time temperature periods, cooling them in a desicator, and then reweighing the pellets.

Effects of Raw Materials on Pellet Properties--

Test results for both drying and preheating are included in this section since the evaluation of the pelletized glass batch included preheat properties. Tables B-3 and B-11 in Appendix B show the compositions and test results obtained in the laboratory experiments using the Dravo and Mars pelletizers, while Table 7 shows test results for pellets made in a 91 cm diameter Feeco pelletizer.

TABLE 7. FEECO PELLET TEST RESULTS (BATCH MS-11)

	Feeco drum				Mars drum			
Drying temp. °C	25	100	100	200	25	100	100	200
Drying time, hr	20	1	2.5	1	20	1	4	16
Average N	15.6	41.2	149.0	206.9	11.7	10.7	48.0	213.7
Standard deviation	1.9	17.6	58.8	22.5	2.9	4.9	6.8	71.5
Average strength, x 10^4 Pa	10.7	26.4	101.0	139.2	6.8	6.8	26.4	132.3

Batches weighing 25 kg were mixed in a P-K type mixer for the Dravo Series (DS) pelletizing experiments. Batches weighing 180 kg or more were prepared in a Voeller mixer (rotating paddle type) for the Mars Series (MS) experiments.

The experimental batch compositional boundaries for the DS and MS batches are shown in Figure 4. The abscissa represents the percentage of fine sand as a fraction of the total sand in the batch. The ordinate represents the percentage of alkaline earth oxides contributed by the burned dolomite in the batch. Raw materials other than the sands, limestone, and dolomite in the batch, that is, nepheline syenite, soda ash, sodium sulphate, and carbocite, were not changed on a percentage basis in the batch compositions. It can be seen that the fine sand in the Boundary I experiments was varied between 5 and 80 percent of the total sand weight, while the burned dolomite was varied from 5 to 80 percent as a percent of the total RD (alkaline earth) content. This corresponds to 3 to 50 percent of the total batch weight for the fine sand and 0.5 to 8 percent of total batch weight for the burned dolomite.

Based on analysis of the DS pelletizing results, the initial (MS) pelletizing batches were selected to fall within the range of 15 to 45 percent fine sand and 5 to 20 percent burned dolomite, as designated by Boundary II in Figure 4. While the batches in the experimental boundary could be pelletized in the Dravo pelletizer, they would not consolidate with any stability in the larger

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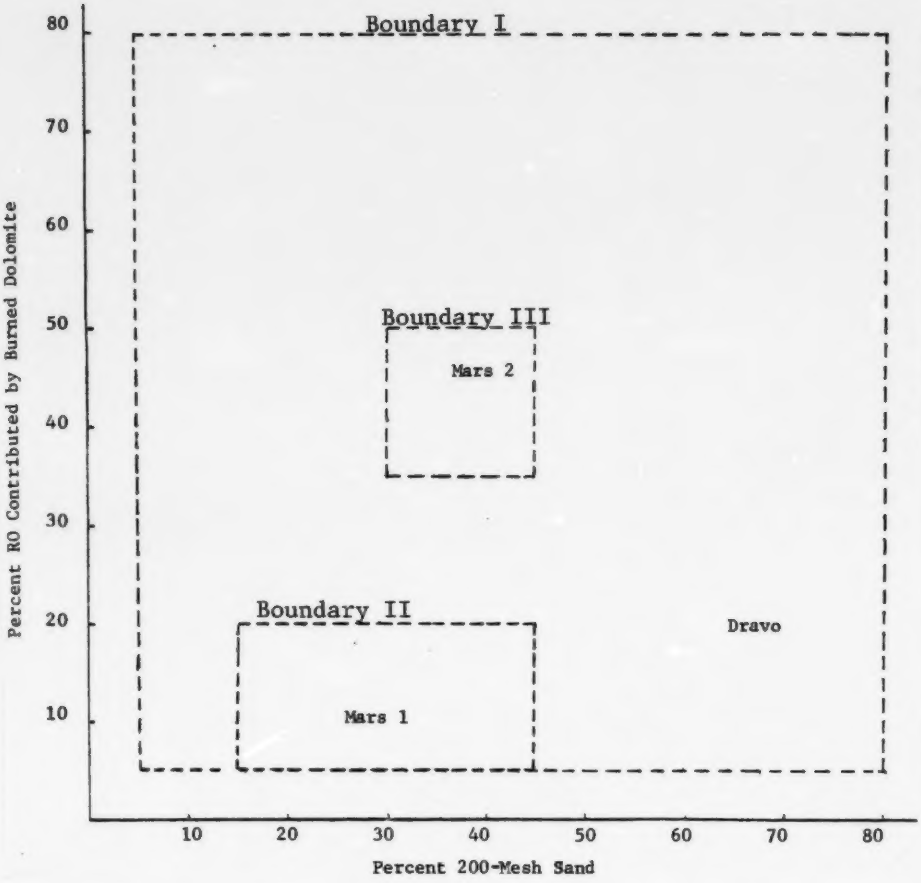

Figure 4. Soda-lime batch experimental boundaries.

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pelletizer. After further experimentation with increased amounts of burned dolomite, another boundary, labeled No. III in Figure 4 was selected which yielded acceptable results in the pelletizer.

As discussed previously under the "Composition and Raw Materials Selection" heading, the particle size distributions of several raw materials in the container glass batch were varied in the DS experiments. Table B-3, Appendix B contains the DS batch compositions, strength results for dried and preheated pellets, and a list of the raw materials used in the batches. Batches DS-1 through DS-17 were dried and preheated in the cup preheater with a soak time of 1 hour at the given temperatures. Batches DS-18 through DS-38A were held for 15 minutes at the given temperatures before they were withdrawn and cooled for strength testing. The air flow rate through the cup preheating tube was 9.3 m^3/hr for both cases.

General conclusions which could be drawn from the DS experiments were that the burned dolomite and fine sand contents of the batches had the most significant influences on pellet strength. Batch pelletizability and green strength of pellets generally increased as the burned dolomite was increased in the batches. Preheated pellet strength increased as the fine sand content of the batches increased.

The effect of raw material changes in the DS batches were evaluated and are presented in Table B-3 Appendix B. This information was used to select raw materials for further pelletizing tests. It was considered necessary to continue experiments in a larger pelletizer in order to scale results for a pilot plant facility. The larger pelletizer used was the Mars unit discussed previously. Batches tested in the Mars unit are subsequently identified as (MS) batches. The materials selected for use in the (MS) batches were combinations of PGS Berkeley No. 1 Dry sand, PGS Berkeley 200 mesh Supersil, National Gypsum York No. 4 limestone, National Lime and Stone No. 40 burned dolomite, Indusmin 340 nepheline syenite, Stauffer soda ash, FMC salt cake, and Shamokin carbocite. Only the percentages of the sands, limestone, and burned dolomite were to be varied in the (MS) batches.

Batches containing binders other than burned dolomite were formulated for trials (Table B-4 Appendix B). The alternate binders included two burned high calcium limes from different locations and a hydrated high calcium lime. The high calcium lime sources allowed the MgO content of the glass composition to be lowered to less than 0.3 percent, which is consistent with most container glass compositions, as discussed later in the Soda-Lime Glass Industry Review in Appendix A.

The dried and preheated strength test results shown in Table B-6 indicate that other pelletizing binders containing lime can be used to make pellets with properties similar to pellets containing burned dolomite.

The first batch to be pelletized in the larger unit after removing the coarse Warner limestone from the batch was DS18 (Table B-3 Appendix B) compositions. Size distributions and dried strengths of the pellet samples taken during this experiment are shown in Table B-5 Appendix B. Due to poor control of the pelletizing water addition and little operator experience, pellet sizes varied considerably throughout the test. However, the batch was relatively easy to pelletize and stability increased as the narrow range for water addition was determined.

Pelletizing results for the (MS) batches are summarized in Table B-7, Appendix B. Coarse sand to fine sand and burned dolomite to limestone ratios indicate the range of the batch compositions in the experiments. The pelletizability of the batches was defined as the relative ease with which the batches could be pelletized, that is, their ability to form seed pellets and stabilize the unit. Pan angles were generally set between 23 and 25 degrees to obtain pellets with diameters between 1.3 and 1.5 cm.

The batches required from 11 to 13 percent water addition. Batches which pelletized well, stabilized within ±0.5 percent of an optimum water addition. In an effort to decrease the moisture requirement of the pelletizing batches, a surfactant (American Cyanimid Aerosol OT) was added at a level of 20 parts per million to batch MS-9 towards the end of the experiment. This level of surfactant costs approximately 5.5 cents per 1000 kg of batch. Theoretically, the surfactant was to decrease the moisture requirement by lowering the surface tension of the pelletizing water, thus changing the contact angle between batch particles and water in the pellets. No further investigation was made as a slight drop in pellet strength was noticed. After the surfactant addition, the surfaces of pellets discharged from the pelletizer were much drier and this could be a handling advantage.

The pelletizing results for batches MS-0, MS-1, MS-3, MS-4, and MS-5 were not favorable; therefore, no pellet samples were taken for testing. Batches MS-2, MS-6, MS-7, and MS-8 were pelletized in the next series of experiments, for which dried strength and weight loss test results can be found in Table B-8 Appendix B. The pellets in these experiments were dried in laboratory electric ovens.

A graph of weight loss versus strength for batch MS-2 is shown in Figure 5. Pellet strength increases very little as the moisture decreases, then increases sharply as the last two percent residual moisture is removed. For batch MS-6 dried at 200°C, pellet strength increased to a maximum then decreased with soak time at this temperature. Air dried pellets were weaker than pellets which had been dried in the oven.

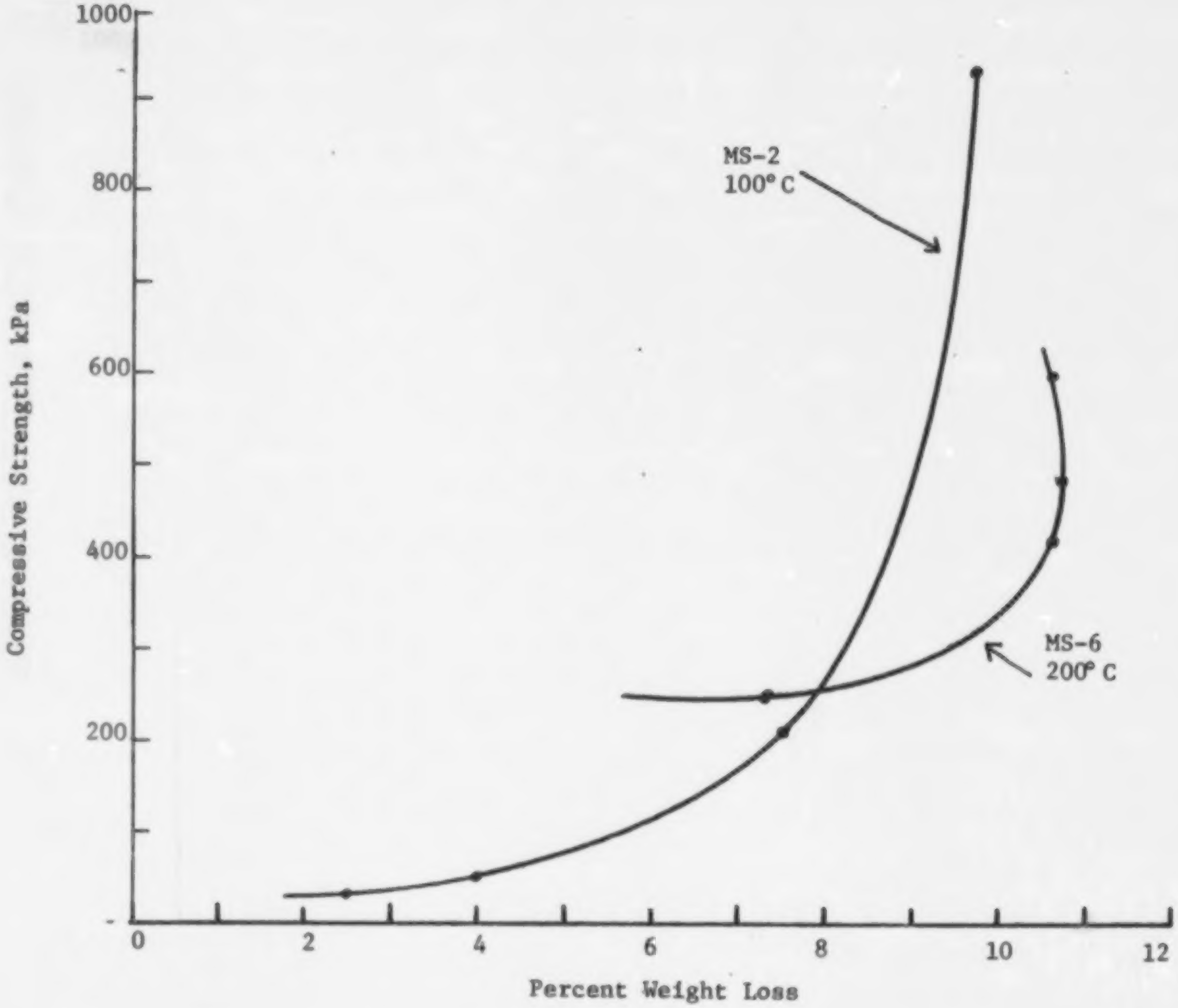

Figure 5. Strength versus weight loss for dried pellets.

Strength test results for dried and preheated pellets and abrasion loss results for dried pellets are presented in Appendix B, Table B-9 for batches MS-2, MS-6, MS-7, and MS-8. The reason for the high abrasion loss of batch MS-8 was believed to be due to incomplete drying of the test samples.

Strength and abrasion test results for batches MS-2, MS-9, MS-10, MS-11, and MS-12 are shown in Appendix B, Table B-10. The high abrasion loss of batch MS-11 was again believed to be due to incomplete drying of the test samples. This series of batches completed the Mars pelletizing experiments.

While not exhibiting the best strength or abrasion test results, batch MS-11 was selected for more extended testing. The decision to select batch MS-11 was based primarily on the relative ease with which this batch could be pelletized in the pelletizer compared to the other batches. A three hour trial of batch MS-11 was conducted to further substantiate the selection of this batch. Samples of pellets were taken during the trial and dried at 200°C. A portion of these samples were tested for strength after drying. The remainder of the pellets were kept stored at 18°C and 50 percent relative humidity for 5 weeks to evaluate their behavior on storage. No visible deterioration of the pellets occurred during storage and no siginificant gain or loss of pellet strength occurred from storage. Results are shown in Appendix B, Table B-11.

Feeco pelletizing trial--Nearly 1800 kg of mixed MS-11 batch was shipped to Feeco International in Green Bay, Wisconsin, for pelletizing trials in a 91 cm diameter disc pelletizer fed from a Vibra Screw batch feeder. Approximately 900 kg of batch was pelletized in a shallow disc configuration with a rim height of 20 cm with little success due to fluctuations in water pressure. Even when a pressure regulator was installed, the pelletizer still would not stabilize for any significant time period, thus, all of the discharged pellets were very weak with drop test numbers ranging from 2 to 5. Pellets made using this shallow pan and air dried overnight, could easily be crumbled between one's fingers.

A pan insert was then added to the pelletizer to increase the rim height to 41 cm, thus changing the rim height to diameter ratio from 0.22 to 0.44. The feed rate in the shallower disc was increased from 340-430 kg/hr to 500-590 kg/hr, the effect of these changes was to produce stronger pellets with wetter surfaces. Drop test numbers ranged from 7 to 12. After drying, the pellets exhibited strengths comparable to laboratory produced (MS) 11 batch pellets (147-196 N crushing force). The pelletizing moisture was estimated to be between 11 and 11.5 percent, and much better stability was achieved with the deeper configuration. Strength test results for MS-11 pellets made in the Feeco and Mars pelletizers are compared in Table 7. The Feeco pellets were somewhat stronger than Mars pellets dried under comparable conditions.

Borosilicate Glass Batch Pelletizing

Raw Materials and Compositions--

Laboratory experiments were run on pelletizing borosilicate glass batch. The purpose was to establish the feasibility of borosilicate pelletizing and to broadly define the raw materials and water content needed.

A common borosilicate, produced for laboratory, kitchen, and lighting ware, contains approximately 80% SiO_2, 2% Al_2O_3, 14% B_2O_3, and 4% Na_2O. A successful pelletizing batch is given below.

TABLE 8. BOROSILICATE GLASS BATCH

		Weight Percent			
		SiO_2	Al_2O_3	Na_2O	B_2O_3
Sand	80.16	80.00	0.07	---	---
Calcined alumina	2.09	---	2.06	---	---
Anhydrous borax	13.33	---	---	4.07	9.18
Boric acid	7.91	---	---	---	4.46
Sodium chloride	0.30	---	---	0.16	---
Total	100.00	80.00	2.13	4.23	13.64

The sand used for these experiments was Pennsylvania Glass Sand Corporation's Oklahoma #1 Dry, a typical glassmaking sand. This was mixed with either 15% or 33% 200 Mesh sand, a very fine silica flour, for better pellet strength. Calcined alumina was Kaiser Chemicals' C-11.

Various raw materials may supply Na_2O and B_2O_3 for borosilicate glass. Sodium carbonate contains Na_2O with carbon dioxide as a by-product. Boric acid and anhydrous boric acid contain B_2O_3. Both Na_2O and B_2O_3 are supplied by sodium tetraborate (borax) in the fixed ratio 1 Na_2O : $2B_2O_3$. Borax may be purchased anhydrous, $Na_2B_4O_7$; or as 5 mol borax, $Na_2B_4O_7 \cdot 5H_2O$; or as 10 mol borax, $Na_2B_4O_7 \cdot 10H_2O$.

The Na_2O and B_2O_3 contribution to a borosilicate batch can come from either sodium carbonate mixed with boric acid or borax and boric acid. Because the ratio of Na_2O to B_2O_3 in typical borosilicate glass is less than 1:2, boric acid, not sodium carbonate, is used to supplement borax. The combination of sodium carbonate and boric acid were not easily pelletized. In the presence of water, used as a pelletizing binder, sodium carbonate and boric acid interact vigorously to release heat and carbon dioxide gas. The result was pellets with the consistency and appearance of bread, filled with pockets of carbon dioxide. The remaining choice of borax and boric acid as batch materials was complicated by the three available types of borax. Since hydrated borax exhibits strange drying behavior, anhydrous borax was used for these experiments. In previous Corning Glass Works' studies, both boric acid and anhydrous boric acid were found to make adequate borosilicate pellets. For this study the anhydrous borax was United States Borax CG-30 and the boric acid was United States Borax granular technical grade. Sodium chloride, Watkins Salt Company AN-35 fine granulated, was added as a glass refining agent.

Seven pelletizing batches were designed and used to explore the following three variations: changing the proportions of normal and fine sand, substituting 5 mol borax for anhydrous borax, and substituting PGS Berkely Fine Dry Special sand for Oklahoma #1 dry sand. The seven batches are shown in Table 9.

TABLE 9 BOROSILICATE GLASS PELLETIZING BATCHES

	Weight percent						
	1	2	3	4	5	6	7
Sand, Oklahoma #1	52.23	53.23	53.23	79.85	67.87		
Sand, Berkely	-	-	-	-	-	53.23	67.87
Sand, 200 mesh	26.65	26.65	26.65	-	11.98	26.65	11.98
Calcined alumina	2.09	2.09	2.09	2.09	2.09	2.09	2.09
Anhydrous borax	-	12.01	13.33	13.33	13.33	13.33	13.33
5 mol borax	18.72	1.87	-	-	-	-	-
Boric acid	82.6	80.9	79.1	79.1	79.1	79.1	79.1
Sodium chloride	0.30	0.30	0.30	0.30	0.30	0.30	0.30

Pelletizing Equipment--

The pelletizer was a 41 cm diameter, 8.9 cm deep Feeco disc. The pelletizer rotational speed was held at 32 rpm for these tests. The disc angle was variable in 2 1/2° increments from 40° to 60° from horizontal and was held at 50°. The positions of the three plows (or scrapers), the water spray, and the batch feed were variable, and for these experiments were positioned as shown in Figure 6. Batch materials were fed to the pelletizer by a Vibra-Screw laboratory feeder and were dispersed in a fan approximately 5 cm wide. The feeder had a variable speed screw turning in a 3.8 cm diameter barrel. The feeder was operated at approximately 27 kg per hour for these tests. Tap water, regulated to 103 kPa (51 psi) pressure, was fed through a Spraying Systems Unijet 1/4 TXI nozzle producing a hollow cone spray pattern of 2.6 kg per hour flow.

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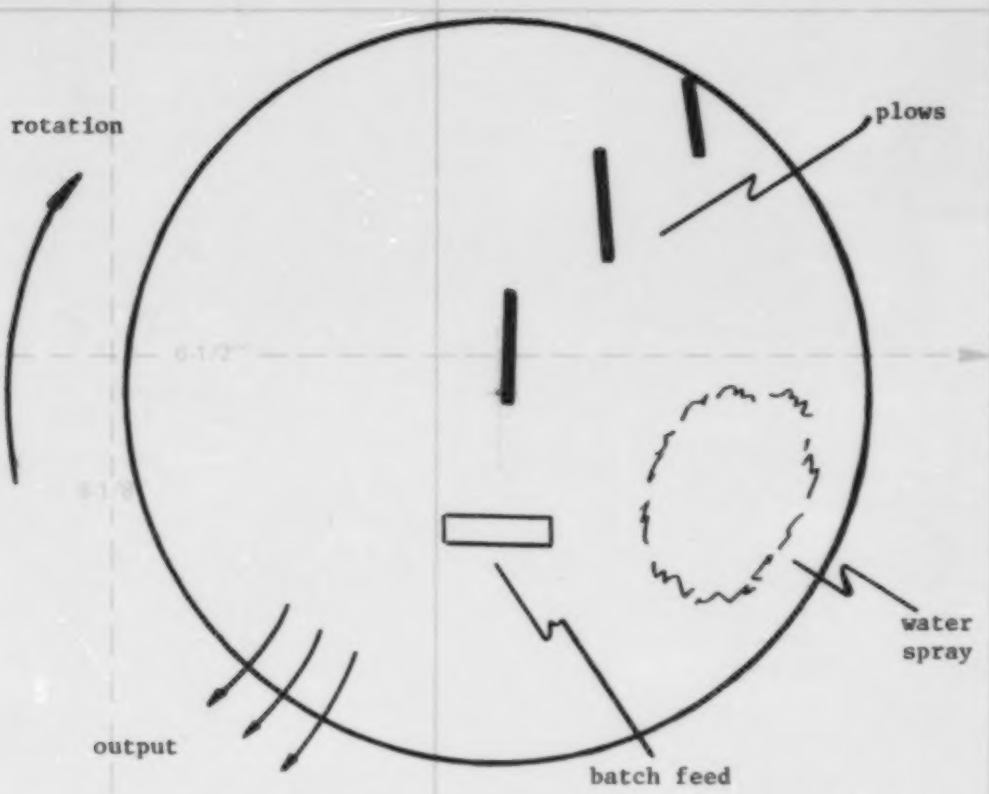
rotation
plows
water spray
output
batch feed

Figure 6. Disc configuration.

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Operating Variables--

The angle of the disc, the rotation rate, and the location of the plows combined to produce a needed material flow distribution on the disc. The best distribution consisted of a clockwise rotation of full-size and near full-size pellets between 7 o'clock and 10 o'clock on the disc, a stream of small pellets and seed pellets falling from 11 and 12 o'clock to 5 and 6 o'clock, and a stream of seed pellets and loose material falling from 1 and 2 o'clock to 4 o'clock. A moist bed of material approximately 0.6 cm thick was allowed to build up on the bottom and sides of the pelletizer. An angle of 50°, a rate of 32 rpm, and plow placement as diagramed (Figure 6) were determined to be effective.

The locations of the batch feeder, the rates of batch material addition, and the water flows must work together not only to produce the correct moisture level in the pellets but also to produce the correct distribution of wet and dry material in the disc. These experiments found that a moisture content of 8 to 10.5% was necessary to make satisfactory pellets. With the water rate fixed at 2.6 kg per hour the batch feed was adjusted between 22 and 30 kg per hour to achieve the desired moisture. The locations of the feeds were coordinated with the material flow pattern described above. The water spray at the 4 o'clock position wetted the loose materials and the "seed" pellets falling through that region. Batch feed at the 6 o'clock position falls upon wet seed pellets and dry or nearly dry full-size pellets in that area.

Results--

Table 10 outlines the qualitative results of these pelletizing experiments.

TABLE 10. BOROSILICATE PELLETIZING RESULTS

Batch number	Sands	Borax	Pellet moisture	General result
1	67% Okla., 33% 200M	100% 5 mol	8%	poor drying
2	67% Okla., 33% 200M	10% 5 mol, 90% anhydrous	8½%	poor drying
3	67% Okla., 33% 200M	100% anhydrous	8½%	good pellets
4	100% Okla.	100% anhydrous	10½%	weak pellets
5	85% Okla., 15% 200M	100% anhydrous	9%	fair strength
6	67% Berkeley, 33% 200M	100% anhydrous	8½%	good pellets
7	85% Berkeley, 15% 200M	100% anhydrous	9%	fair strength

Anhydrous borax was determined to have better drying behavior than 5 mol borax. Although 5 mol borax was pelletized successfully, the exfoliation of the 5 mol borax on drying produced weaker pellets with a granular surface. The same results were obtained when 10% of the borax was 5 mol. The fraction of 200 mesh sand mixed with Oklahoma sand was changed from 0 to 15% and then to 33% 200 mesh sand. An increase in pellet strength was demonstrated with increasing fine sand. Without fine sand (Batch 4), wet pellet strength was so poor that many pellets did not survive the tumbling action in the pelletizer. With 33% 200 mesh sand, wet pellets easily survive a two foot drop test. With 15% 200 mesh sand, the strength was intermediate. There was no observable difference between Oklahoma sand with rounded grains, and Berkeley sand with angular grains.

To summarize, batches 3 and 6 made satisfactory borosilicate pellets. These batches contained 67% normal glassmaking sand with 33% 200 mesh sand, anhydrous borax, boric acid, calcined alumina, and sodium chloride. It was concluded that hydrated boraxes and sodium carbonate are not desirable for borosilicate pellets.

Briquetting of Soda Lime and Borosilicate Glass Batch

Briquetting tests of a standard soda-lime container glass batch and two borosilicate glass batches were conducted at the K. R. Komarek Incorporated facilities at Elk Grove Village, Illinois. These batches contained coarse raw materials and no binder as such. The batch compositions are listed in Table 11.

TABLE 11. BRIQUETTING BATCHES

Soda Lime Container Glass Batch

	Percent
Berkeley #1 sand	56.2
Limestone	16.9
Nepheline syenite	6.9
Soda ash	19.4
Salt cake	0.5
Carbocite	0.1

Borosilicate Glass Batches

	Percent ABX	Percent 5 mol
Oklahoma #1 sand	77.1	73.0
Anhydrous borax	12.9	---
5 mol borax	---	17.1
Boric acid	7.6	7.6
Alumina	2.1	2.0
Sodium chloride	0.3	0.3
Sodium nitrate	0.05	0.05

Oval shapped briquettes (4.4 cm x 2.2 cm x 1.3 cm) were made on a model B-100 briquetter with a roll diameter of 13 cm (5.1 in) and roll width of 5 cm (2 in). Roll speed was approximately 4 rpm. Water was added to the batch in a muller type mixer.

Soda lime glass batch was briquetted with roll separating forces from 4450 N (1000 lb.) to 8900 N (2000 lb) and moisture content from 4% to 8%. At 4% moisture, many briquettes were broken in the 30 cm drop to a collecting box. At 6% moisture and above, the briquettes survived the drop. Green briquettes could not be crushed between two fingers, but were easily broken in bending.

After air drying for one hour, briquettes produced with 6% or more moisture could not be broken by hand. The crushing strengths of air dried briquettes are listed in Table 12. It should be noted that these numbers cannot be directly related to pellet crushing strengths because of differences in the geometry of the load bearing areas in strength testing.

TABLE 12. SODA LIME BRIQUETTING TEST RESULTS

Test no.	Percent water addition	Roll pressure x 10^4 Pa	Single briquette air dried fracture load[a] N
1	4	689	89
2	4	13,789	156
3	6	689	334
4	6	1,035	338
5	6	1,379	361
6	7	689	379
7	7	1,035	357
8	7	1,379	406
9	8	689	422
10	8	1,035	397
11	8	1,379	---

[a] Briquettes placed between platens

The two borosilicate glass batches differ only in the boron sources. The ABX batch was briquetted successfully at 5340 N of roll force with 3, 4, and 5% water, but was too wet at 8%. The green briquettes could be crushed easily between thumb and forefinger. After 30 minutes of air drying they could not be crushed but would still snap at tension. With further drying in a 150°C oven, they could not be snapped. The 5 mol batch was briquetted successfully at 4450 N of roll force with 2, 3, and 4% water, but was too wet at 6%. The green strength and air dried strength were comparable to the ABX briquettes; however, the 150°C oven dried strength was considerably weaker and there was evidence, inside and out, of 5 mol borax popping.

DRYING AND PREHEATING

General Considerations

Preheating of glass batch is not a new concept, and over the past 25 years has been considered by various companies and individuals as discussed in Appendix A. Initial interest was directed more towards presintering the glass batch to promote certain chemical reactions between the glassmaking materials, as opposed to utilizing waste heat. Practically every conceivable method for heating powders or agglomerates appears in the patent literature, much of it predates 1950. This diversity may have deterred the development of preheating technology, even though it has become apparent in recent years that the rising cost of energy makes preheating potentially more economical than conventional glassmaking processes. Once loose glass batch is consolidated, it can be preheated if the proper combination of materials are used. Since pelletizing adds water to the glass batch, a drying step must be included, either as part of preheating or aside from it. A preheating system should be capable of being utilized with either new or existing melting furnaces, thus making the concept readily acceptable to industry. It is desirable that the preheating system operate at a high thermal efficiency; that is, recover a significant amount of the energy put into the system. Preferably, the energy for preheating should come from the hot gases being exhausted from the existing furnace.

Preheating Equipment--

Preheating can be accomplished with many different types of equipment, that is, rotary kilns, drop towers, grate kilns, rotary hearths, and other types. However, when one considers all aspects of a preheat and pollution control system, the vertical shaft furnace appears more applicable than others. Characteristics of preheating equipment considered important are:

utilization of waste heat,
high thermal efficiency,
mechanical reliability,
flexibility with regard to output,
occupy minimum floor space and,
minimum capital and operating cost.

In this regard, vertical countercurrent shaft furnaces have historically been simple devices, and low in both investment cost and energy loss. In its simplest form, the shaft furnace is a refractory-lined vertical cylinder filled completely with uniformly sized agglomerates. A discharge mechanism, called a grate, is located at the bottom along with a means for introducing hot gases. Cold or wet materials are introduced at the top. Material flows by gravity down the shaft, the rate being controlled by the grate mechanism at the bottom. Materials are heated by the countercurrent flow of hot gases up the shaft. The two major factors in successfully designing a shaft furnace include uniform movement of the material downward and uniform flow of the gases upward. This is necessary to promote controlled, uniform heating in the furnace.

Shaft furnaces contain very few moving parts, occupy a minimum of plant space, and efficiently utilize energy. Shaft furnaces usually operate at 70% thermal efficiency or higher. The reduced size of shaft preheaters is a particularly attractive feature since many existing plants contain a minimum of floor space. A shaft preheater could be located near the feed end of the melting furnace, supported above it if necessary, similar to the way that large metallic recuperators are positioned today by some glass manufacturers.

Presently, equipment is not available which can be directly applied to preheating glass batch; however, there is shaft kiln technology available to aid in the design of specific equipment for use by glass manufacturers.

Preheat Temperature--

The major problems associated with the operation of a preheater at elevated temperatures are primarily related to agglomerate integrity and agglomerate sticking. Agglomerate integrity refers to the ability of the agglomerate to pass through the shaft furnace without being crushed or broken by the overburden or significantly abraded by contact with other agglomerates. Sticking occurs when high temperature liquid phases are developed at the pellet surfaces which cause fusing of agglomerates in contact with each other. Sticking could cause clusters of agglomerates to form which can bridge the discharge opening. Thus, many shaft kilns employ mechanical cluster breakers to handle this problem if it occurs.

Degradation of agglomerate integrity depends a great deal on the mechanical and chemical binding forces which hold the agglomerate together. When a preheater is operated at higher temperatures (at about 800°C) new solid state bonds may form. The method of agglomerate production, the binders used, and the characteristics of the raw materials determine the integrity of the agglomerate as it is heated. Obviously, it is important to utilize an agglomerate which possesses integrity up to the expected preheat temperatures.

Pellet Integrity--

In this program, pelletizing was the method used to agglomerate the batch. Generally speaking, it is known that a pellet made from finer glass-making materials, utilizing calcined dolomite as a binder, can be continuously heated to 800°C under conditions similar to those expected in commercial vertical shaft furnaces.

Pellet integrity can vary, depending on the test conditions, as discussed in the previous pelletizing section and the method for producing a pellet can affect its microstructure, density, and strength.

Also important for pellet integrity are the physical and chemical forces binding the individual glass-making raw materials together. The binder system will be determined primarily by its cost, availability, and its performance under preheating conditions. Many binders are extremely good at low temperatures but degrade rapidly above 250°C. The binder must contribute to pellet integrity up to temperatures where chemical reactions begin to occur, promoting high temperature bonding of the glass batch materials.

The third major parameter of pellet integrity involves the physical and chemical characteristics of the glass-making raw materials. Currently, rather coarse raw materials are used by many glass manufacturers; however, they are not easily pelletized. Since dusting will not be a problem if pellets are used in a glass-melting furnace, raw materials should be selected based on pelletizing and preheating properties.

Prereaction--

When batch is heated, intermediate high soda fluid phases are formed which then react with silica. In a glass melter, where cold batch is introduced directly into the high temperature environment, this intermediate liquid can be observed running down the batch piles. As a result of the high temperatures and the short contact time with the rest of the batch, the liquid has very little opportunity to react with the silica. This results in a silica-deficient liquid which initally segregates from the silica-rich batch. Homogenization entails remixing these liquids and dissolving the silica-rich liquid in the more fluid phase at higher temperatures.

Compounds formed between Na_2O, SiO_2, and CaO at the lower preheating temperatures should reduce these homogenization problems. In addition, during preheating some CO_2 will be released from the batch, and its removal from the batch should reduce the refining time.

Pellet strength, Table 6, drops to a minimum at 650°C and then rises sharply at 750°C. The formation of a metasilicate compound between the soda and silica is the most likely explanation for the strength increase. Visual inspection of pellets also showed a change in character. The pellets appeared denser and the formation of a liquid phase was evident. Eutectic formation occurs as low as 725°C in the soda-lime-silica systems between $Na_2Ca_3Si_6O_{16}$, SiO_2, and Na_2SiO_3. At 740°C, a eutectic formation occurs between $Na_2Si_2O_5$, $Na_2Ca_2Si_3O_9$, and $Na_2Ca_3Si_6O_{16}$.

The amount of prereaction which can occur depends upon the surface area of the raw materials (particularly silica), materials combination, preheat temperature, and soak time at elevated temperatures.

Cullet and Minor Additives--

In modern glass container manufacturing processes, cullet comprises from 10 to 25 percent of the total furnace feed stock. Other segments of the glass industry may use even higher amounts. The remainder is mixed batch formulated from selected raw materials. The mixed batch contains the major constituents such as sand (silica), soda ash (sodium carbonate), and lime (either calcium oxide, calcium carbonate, or calcium-magnesium carbonate), and minor constituents such as sodium sulfate, baryte (barium sulfate), and carbon for fining, or cerium, cobalt, or selenium for decolorizing the glass. Although some experiments to study the effect of batch and cullet mixtures on the melting phenomenon have been conducted (4) with a hot stage microscope, a systematic study to evaluate the effect of an agglomerated batch cullet mixture on glass homogeneity has not been made on macro systems. No patents have been granted which indicate that the separate charging of loose batch and cullet into the melting furnace improves glass quality compared to a mixture of batch and cullet, so homogeneity is not anticipated to be a problem area. Cullet should not be passed through a shaft preheater at elevated temperatures but should be fed separately. It is not desirable to use cullet as part of the pelletized batch.

Cup Preheater Tests

A majority of the bench-scale preheat experiments were conducted initially in a cup preheater in which hot gases were passed through a basket of pellets which were electrically-heated. The following section describes the equipment used, the operating procedures, and the test results.

As a result of the work conducted by Columbia Gas, it was recognized that test results for preheated pellets were more meaningful and correlated more closely with the results of a moving-bed preheater experiments when the pellets were heated by a hot gas stream flowing through the bed of pellets, as opposed to heating the pellets with no gas flow. Therefore, an apparatus was designed and constructed which would permit several lots of pellets to be heated under flowing gas conditions. Under these conditions, heating of the pellets occured predominately by convective heat transfer, especially at lower temperatures. This more closely approximates the conditions in a moving bed and the time used for these tests approximated the time expected in a moving bed.

A flowing atmosphere through a pellet bed also removes CO_2 as it evolves from the pellets. Some of the reactions occurring can be influenced by the amount of CO_2 present, which in a static environment could be significant since CO_2 is heavier than air and could lie in the bottom of a crucible full of pellets. It is not clear how important this effect might be, but by flowing gas through a bed of pellets, the effect is minimized.

Equipment Design--

The cup preheater is shown schematically in Figure 7. It included an electrically heated (C) insulated furnace (F) which contained a stainless steel heating shaft (A). A segmented basket (B) containing the pellets to be heated, was inserted into the bottom of the furnace shaft. Electrically heated air (D,E) passed down the tube and through the basket of pellets. Figure 8 shows the segmented basket for holding pellets. Approximately 75 pellets were placed in each of eight basket sections. Thermocouples were attached to the basket to periodically monitor temperature in the eight basket sections.

Operating Procedure--

The cup preheater was operated in two modes: step-wise heating or heating at a single temperature. The temperature was controlled by set-point controllers and was manually stepped up to a desired soak temperature with the pellet basket in position. The preheater was also brought to the desired temperature after the basket of pellets was inserted and allowed to come to equilibrium at that temperature. While drying and preheating experiments were done both ways, it was normally operated in the stepped mode.

The normal operating procedures were to:

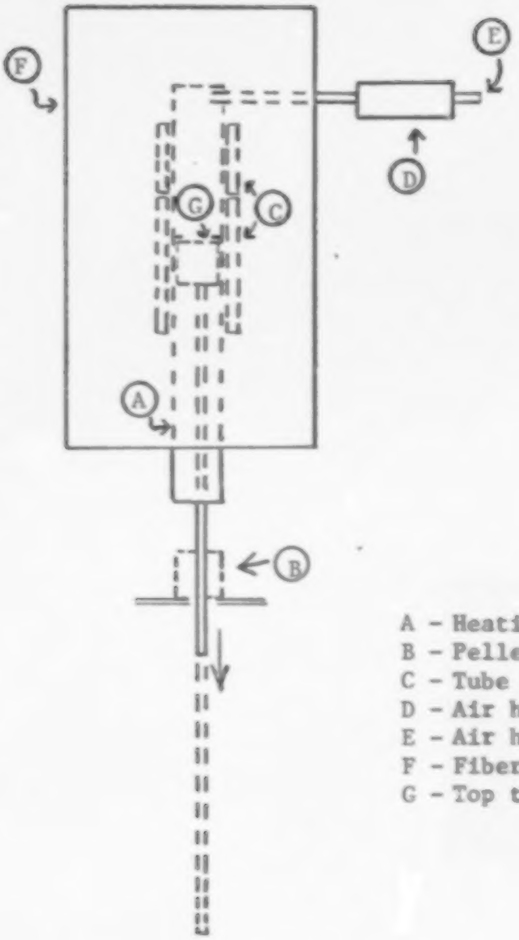
(a) Fill completely the 8 compartments in the baskets with pellets.

(b) Insert the basket into the tube.

(c) Raise the temperature in steps to 100°C or 150°C (at 20°C/min).

(d) If the pellets were not previously dried, remove the basket and take the dried pellet samples from each compartment for strength testing. Reinsert the basket and continue stepped heat-up to the desired temperature.

(e) Soak at the desired temperature for approximately 15 to 60 minutes and then basket and collect pellet samples from each compartment.



A - Heating shaft
B - Pellet holding basket
C - Tube heating elements
D - Air heating element
E - Air hose connection
F - Fiberfrax insulated outer shell
G - Top thermocouples

Figure 7. Pellet cup preheater.

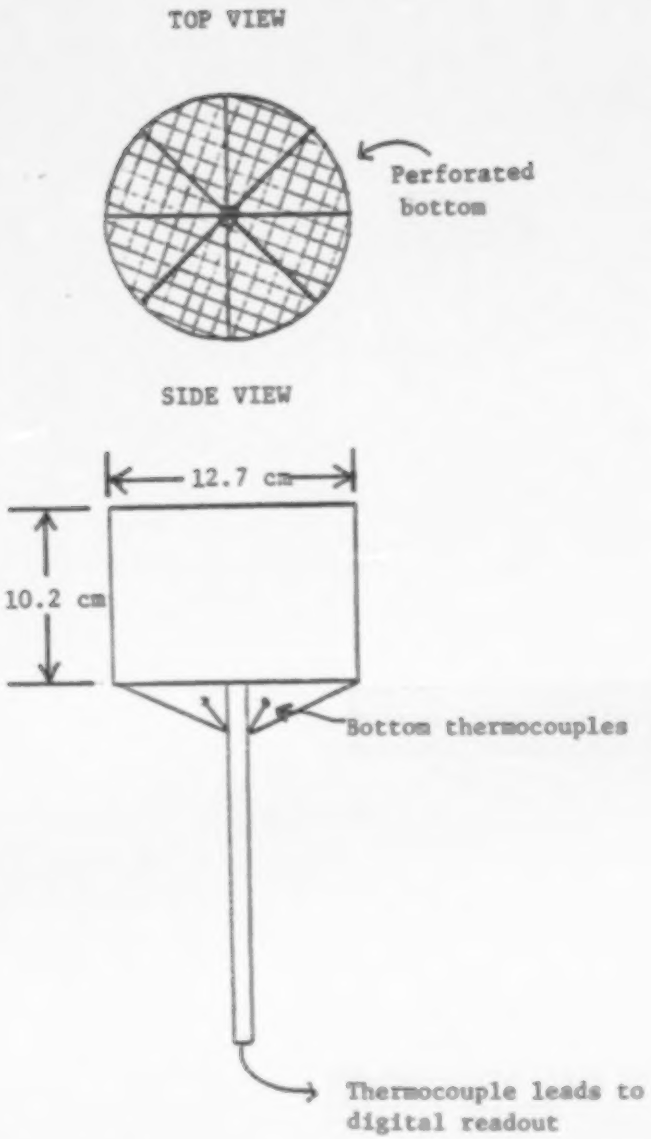

TOP VIEW
Perforated bottom
SIDE VIEW
12.7 cm
10.2 cm
Bottom thermocouples
Thermocouple leads to digital readout

Figure 8. Cup preheater basket.

Test Results--

A typical heat-up schedule is given in Figure 9. The results of pellet property measurements from the drying and preheating tests were reported earlier, and were used to guide the pelletizing studies.

Drying--The cup preheater was used to conduct initial drying tests. Early results obtained on the DS-1 pelletized batch containing coarse limestone created drying problems, due to limestone decrepitation. Table 13 shows strength results obtained in the cup preheater on pellets made from this batch. As can be seen, pellets increase in strength as they are dried at progressively higher temperatures up to 200°C. Above 200°C strength begins to decrease. This increase in strength up to a maximum and then a gradual decline in strength is typical of all soda-lime glass batches containing burned dolomitic lime as a binder. Figure 10 illustrates that 75% of dried strength at 100°C was achieved in one hour.

TABLE 13. STRENGTH OF PELLETIZED BATCH DS-1 FOR NOMINAL DIAMETER OF 1.2 cm

Test no.	Drying temperature, (°C)	Drying time, (hours)	Average strength for ten pellets x 10^4 Pa
1	25	0	18
2	25	48	43
3	100	0.5	53
4	100	1	217
5	100	2	233
6	200	1 (plus time at test no. 5)	367
7	250	1 (plus time at test no. 6)	232

Once the coarse limestone was removed from the batch, drying was done at elevated temperatures (up to 400°C) with no popping, although some cracks were visible in pellets which were inserted directly into the hot gas stream at these elevated temperatures. Table 14 lists the results of drying experiments conducted on wet pellets (MS 11) immediately after pelletizing. These tests were conducted in the cup preheater at a flow rate of 18.7 m^3/hr (660 SCFH). The wet pellets were placed directly into the hot gas at 250, 350 and 400°C. No popping was observed at any of the drying temperatures. Significant cracking and some spalling of pellets occurred during the 400°C test. Although pellets can apparently

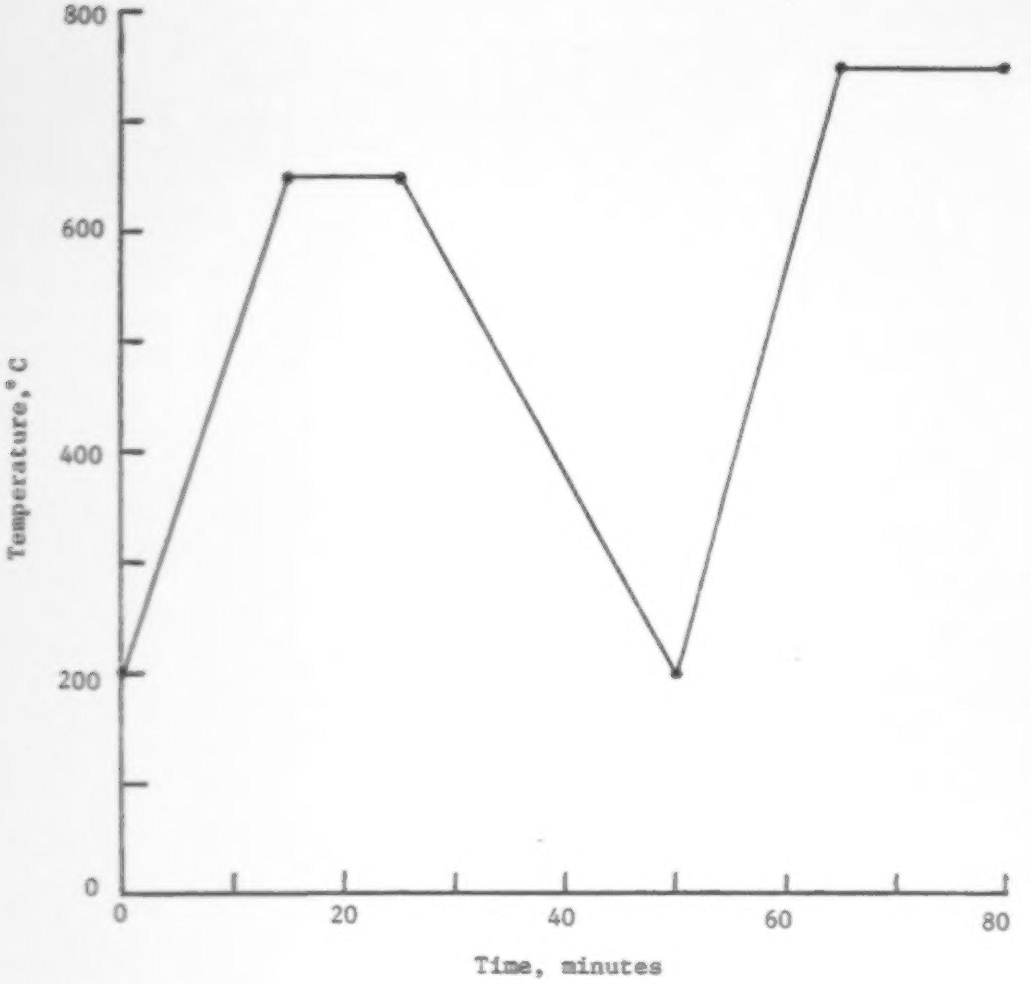


Figure 9. Cup preheater heat-up schedule.

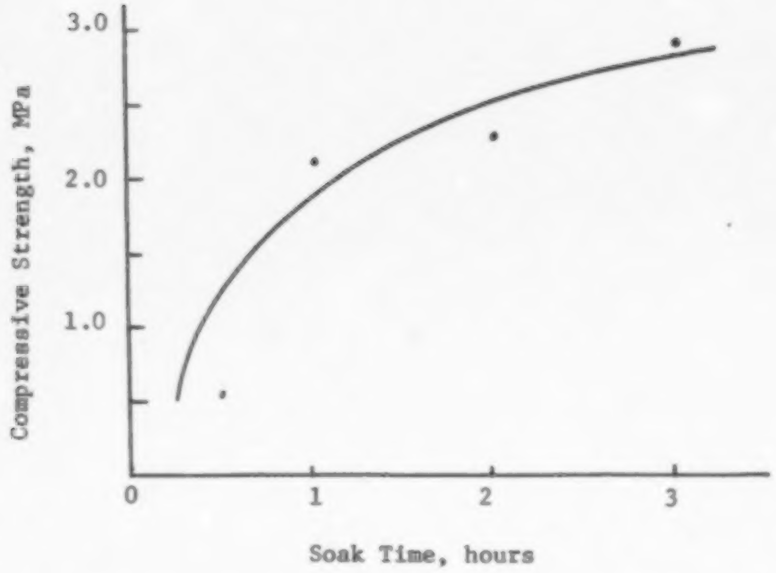


Figure 10. Pellet strength versus drying time at 100°C.

TABLE 14. MS-11 DRYING TESTS

Drying temperature, °C	250	350	500
Flow rate, m^3/hr	18.7	18.7	18.7
Average crushing force, N	54.9	43.1	56.8
Standard deviation	13.7	8.8	7.8
Average strength, x 10^4 Pa	44.1	30.4	36.2
Percent weight loss	11.2	12.1	11.6
Percent spalling loss (-10 mesh)	2.6	0.3	0.6
Comments	Pellets very wet starting; no cracks or popping	Few cracks; no popping	No popping; all pellets cracked; considerable spalling of large pieces from pellet surfaces

withstand drying temperatures as high as 350°C, the test results indicate lower drying temperatures (150°C) may yield higher pellet strengths.

Preheating--Results of pellet property measurements from the preheating tests were given in the "Consolidation" section since they were needed to guide the selection of raw material combinations and pelletizing conditions. A primary objective of the pelletizing work was to produce pellets having reasonable strength after being preheated to temperatures above 600°C.

Figure 11 illustrates the change in strength of several batches after preheating to different temperatures and then cooling. The strength drops off initially and then increases as prereaction and liquid phase sintering occurs. Strengths were generally higher at 750°C than at 600°C for compositions containing enough fine silica. If prereaction and sintering do not occur to a sufficient degree, strength decreases even further. A minimum strength for the preheated pellets seemed to occur around 600°C.

Static Bed Preheater

The preliminary preheating studies in the cup preheater provided the information needed to screen the initial pelletized batches. However, this equipment was unsatisfactory for conducting drying and preheating tests on larger quantities of pellets under gas flow conditions and preheating rates relevant to the pilot-scale moving bed. Also, the cup preheater was not suitable for conducting pollutant capture studies. Therefore, it was decided that a static-bed preheater, heated with combustion products, would be built and operated to conduct these additional tests. The cup preheater was dismantled and its components used, as appropriate, in the static-bed preheater. The following section describes the apparatus, its operation, and presents the test results.

Equipment Design--

Several iterations of equipment design were involved before settling on the static-bed preheater which was built. Initially, consideration was given to the design of a continuous, moving-bed preheater which would operate at a pellet feed rate of approximately 113 kg/hr (250 lb/hr). It was decided that the time and cost of construction and operation of this equipment was not warranted.

Figure 12 is a side view of the preheat system. It consisted of a combustion system, hot gas transfer lines, the static bed preheater, and a basket for holding pellets that could be loaded into the hot preheater.

The combustion system delivered metered air and gas to an excess air burner which was fired into a small combustion chamber,

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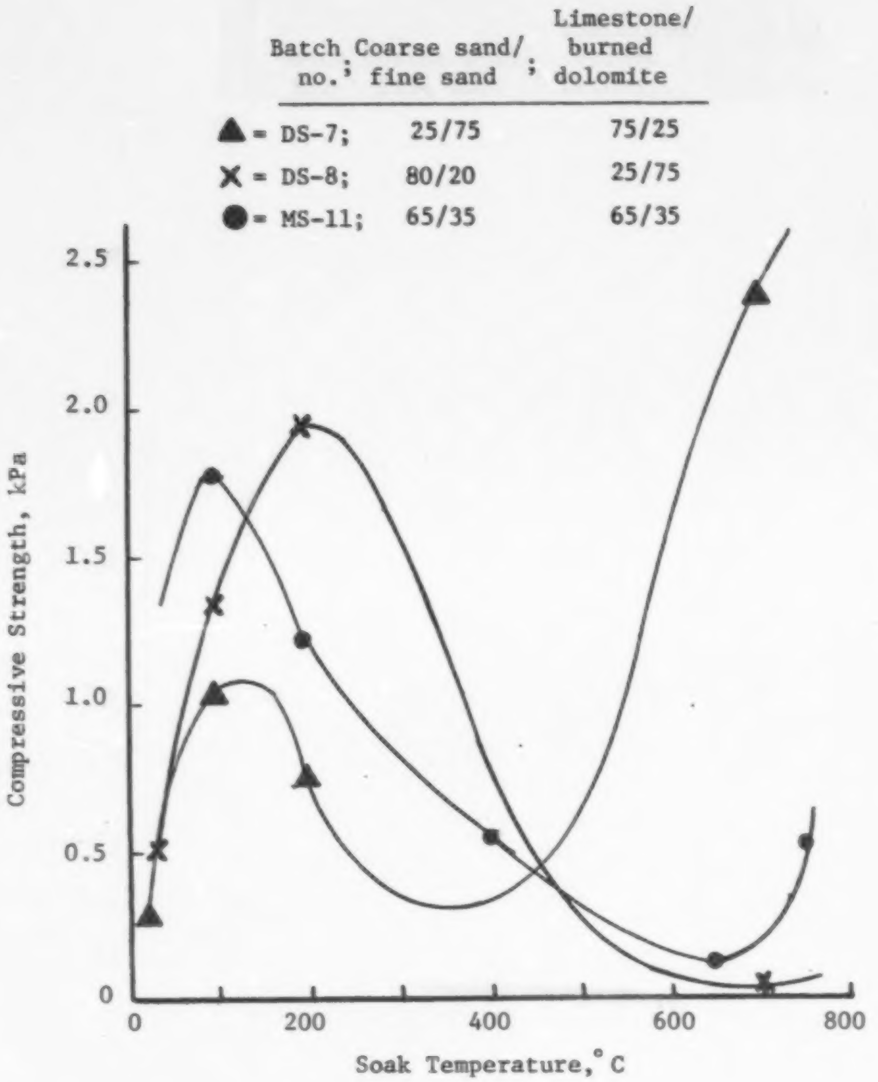

Figure 11. Cold strength of preheated pellets with coarse sand, fine sand, and burned dolomite varied.

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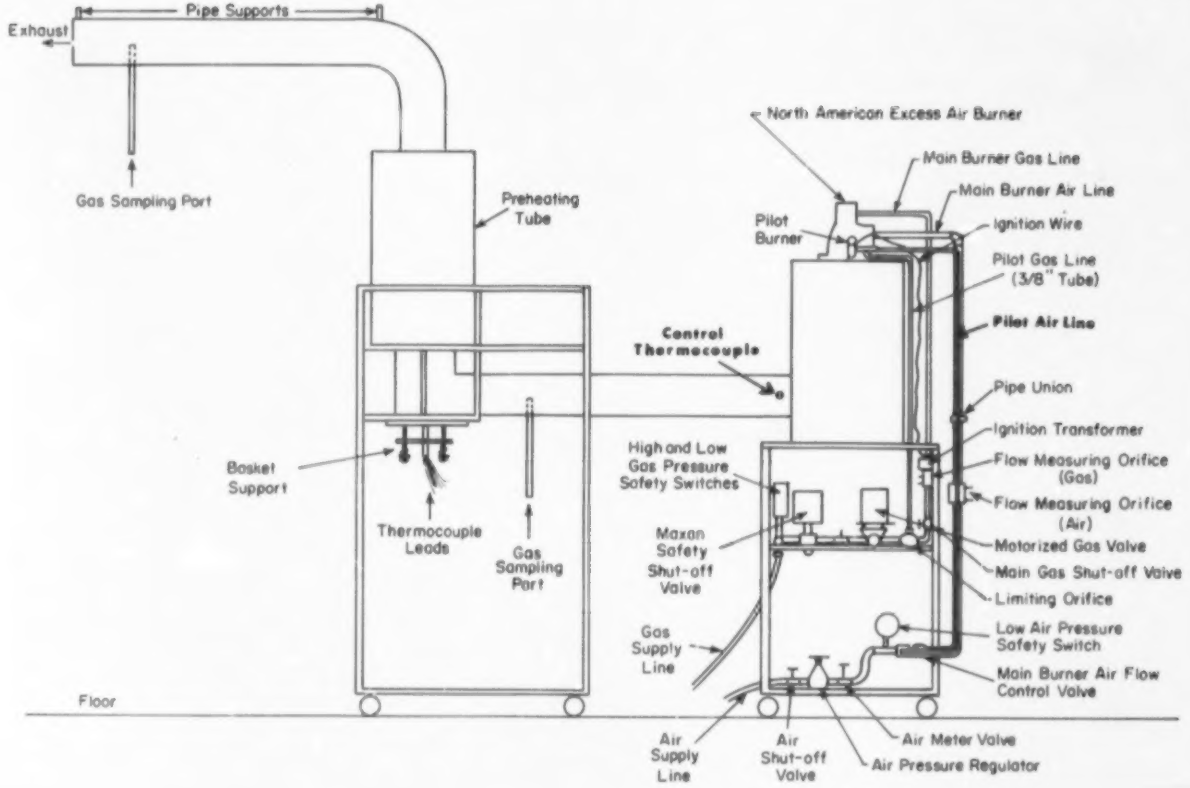
Exhaust
Pipe Supports
Gas Sampling Port
Preheating Tube
Basket Support
Thermocouple Leads
Gas Sampling Port
Floor
Control Thermocouple
North American Excess Air Burner
Main Burner Gas Line
Main Burner Air Line
Pilot Burner
Ignition Wire
Pilot Gas Line (3/8" Tube)
Pilot Air Line
Pipe Union
Ignition Transformer
Flow Measuring Orifice (Gas)
Flow Measuring Orifice (Air)
High and Low Gas Pressure Safety Switches
Maxon Safety Shut-off Valve
Motorized Gas Valve
Main Gas Shut-off Valve
Limiting Orifice
Gas Supply Line
Low Air Pressure Safety Switch
Main Burner Air Flow Control Valve
Air Supply Line
Air Shut-off Valve
Air Meter Valve
Air Pressure Regulator

Figure 12. Side view of static bed preheating system.

from which the hot gases passed through 15.2 cm diameter stainless steel tubing to the preheater. Temperature was controlled by varying the gas flow. A control thermocouple, located at the exit of the combustion chamber, provided a signal through a controller to the motorized gas valve positioner. This system was selected in order to minimize changes in the flow rate of the combustion products.

Figure 13 is a layout of the combustion train. There were three lines: air, gas, and pilot. The air was supplied from either a blower or compressed air. Also included was a shutoff valve, a limiting orifice valve for adjusting air flow, a metering orifice for measuring air flow, and a low pressure switch. The gas line consisted of a shutoff valve, gas at 9.8 kPa, high pressure and low pressure switches, a safety shutoff valve, a motorized gas valve, a metering orifice, and a shutoff valve. The pilot line contains a pilot gas ratio regulator, gas pressure reducing regulator, gas solenoid valve, ignition transformer, pilot set, and a gas valve.

An excess air, natural gas burner [rated by the manufacturer at 127,000 Btu/hr with a 2.6 kPa (6 psi air pressure drop)] was used. Provisions existed for introducing SO_2 and particulate into the air line.

Combustion gases were maintained at temperatures up to 1000°C. The hot gases were then transferred to the preheater through a 15 cm stainless steel tube which was wrapped with Fiberfrax and glass fiber insulation to minimize heat loss. Temperature drops from 50° to 200°C occurred depending on the temperature and flow rate of the hot combustion gases. Provisions were also made for taking SO_2 and particulate samples from both the inlet and the exhaust.

The preheater itself was approximately 230 cm high and contained a stainless steel tube 15 cm in diameter by 100 cm high. The pellet basket was inserted into this tube. A spacer ring was welded to the inside of the tube and the top rim of the basket was butted against the ring to form a seal during operation. Combustion gases entered at the bottom of the preheater and exited at the top. Pressure taps existed above and below the basket location to measure the pressure drop across the pellets, using a U-tube manometer.

Figure 14 is a schematic of the pellet basket used in the static bed preheater. It was made of stainless steel and was approximately 15 cm in diameter and 25 cm high. A support and loading rod through the center of the basket contained seven thermocouples for measuring temperatures. The basket had a flange at the bottom which sealed against the flange of the preheater. A gasket was used to effect a pressure seal.

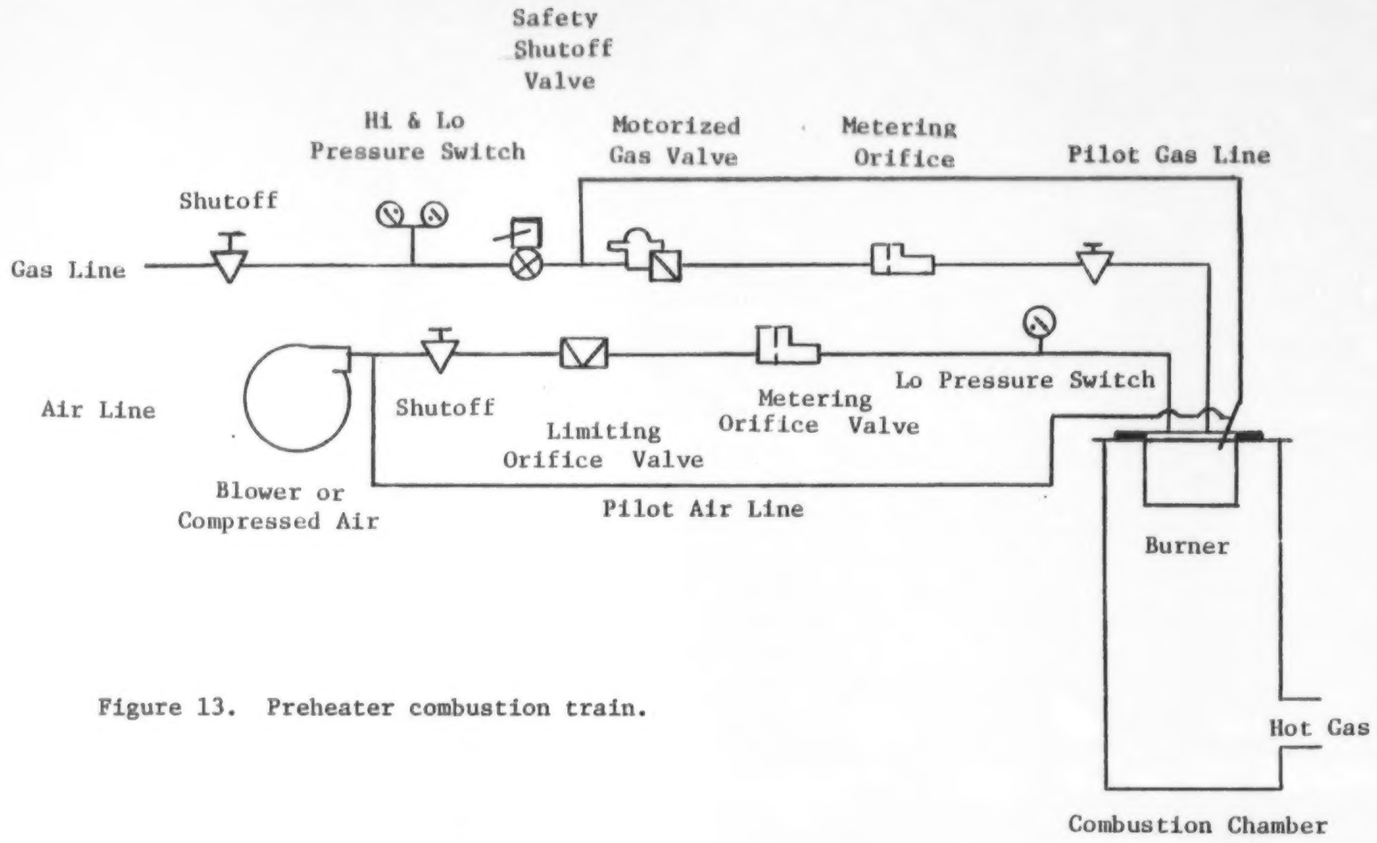
Safety
Shutoff
Valve
Hi & Lo
Pressure Switch
Motorized
Gas Valve
Metering
Orifice
Pilot Gas Line
Shutoff
Gas Line
Air Line
Shutoff
Limiting
Orifice Valve
Metering
Orifice Valve
Lo Pressure Switch
Blower or
Compressed Air
Pilot Air Line
Burner
Hot Gas
Combustion Chamber

Figure 13. Preheater combustion train.

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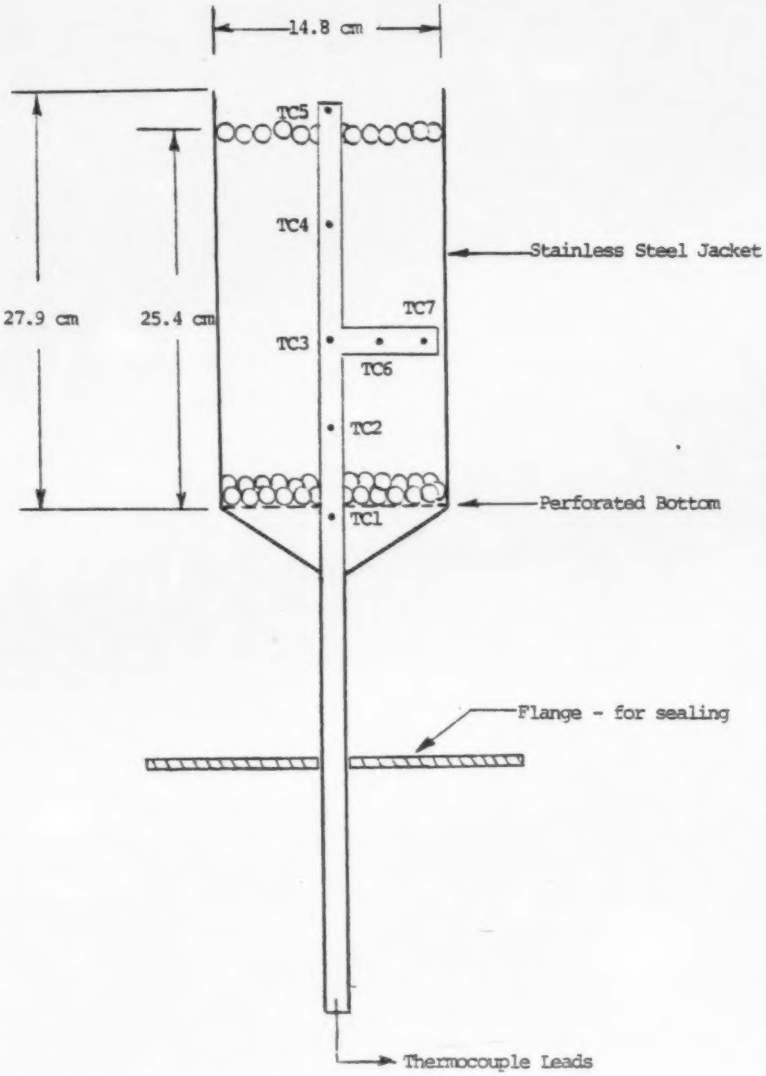
14.8 cm
27.9 cm
25.4 cm
TC5
TC4
TC7
TC3
TC6
TC2
TC1
Stainless Steel Jacket
Perforated Bottom
Flange - for sealing
Thermocouple Leads

Figure 14. Static bed preheater basket.

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Operating Procedures--

Based on shakedown tests conducted at different temperatures and flow rates of the combustion gases, a general relationship was defined between the temperature exiting the combustion chamber and the preheater temperature. The general procedure consisted of preheating the system to an equilibrium condition at the desired drying or preheating temperature. This would take several hours with the system operated at high gas flow rates. Once the temperatures stabilized, the desired flow rates would be set and the system allowed to equilibrate at these conditions. The plate attached to the flange at the bottom of the preheater would be removed and the basket, filled with wet or dried pellets inserted and clamped at the flange. Temperatures were recorded continuously over the entire test period. Measurements of gas and air flow to the burner were taken regularly along with the pressure drop across the pellet basket. During the tests, gas samples were drawn and their SO_2 contents measured by gas chromotagraphy. CO_2 was measured with a Fyrite apparatus. Once the system had thermally stabilized (approximately 30 minutes), SO_2 pollutant capture measurements were taken. Each test took approximately 4 hours to complete.

Drying Tests

Drying tests were conducted on moist MS-11 pellets which had been stored in polyethylene bags. The results were comparable to those found previously when freshly formed pellets were dried in the cup preheater.

For each of the drying tests, the preheater was heated to the desired temperature at a given flow rate, and the basket containing moist pellets (filled to 2.5 cm above the radial arm in the center) was inserted into the preheating tube and allowed to come to equilibrium. The basket was then withdrawn from the tube and air cooled. Finally, the pellets were inspected for signs of cracking or popping. Tests were conducted at 300°C and 34.0 m^3/hr, 300°C and 45.3 m^3/hr, and at 400°C and 45.3 m^3/hr. None of the pellets appeared to have cracked or popped after the drying tests. Figures 15, 16, and 17 show the distribution of temperatures in the basket versus time for each of the drying tests.

Table 15 gives the average compressive strength of the pellets dried and preheated in the static bed preheater. The strength of the pellets dried in the static bed preheater are consistent with those reported earlier.

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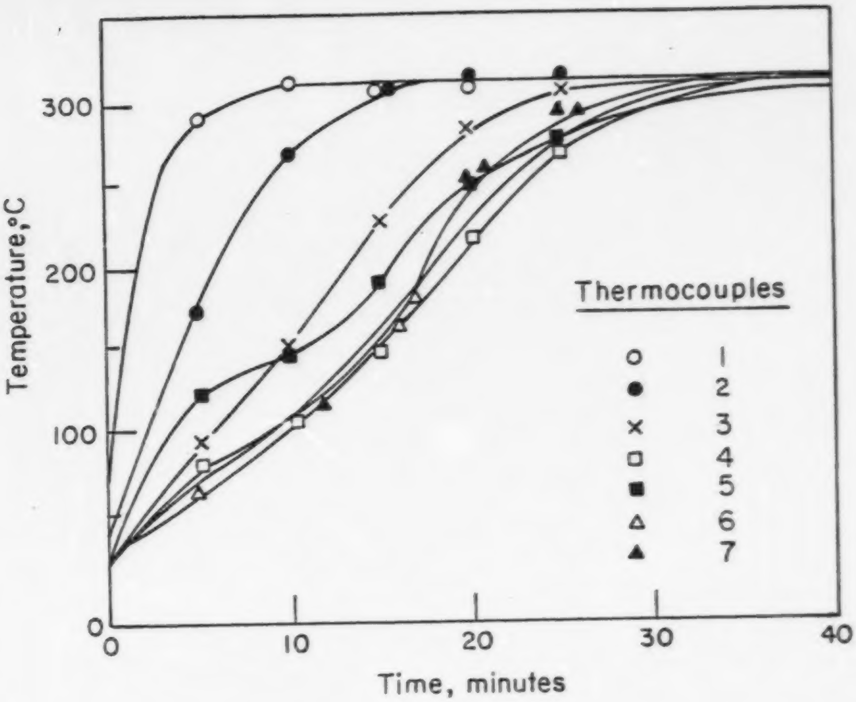

Figure 15. Thermocouple readings for drying at 300°C and 45.3 m^3/hr flow rate.

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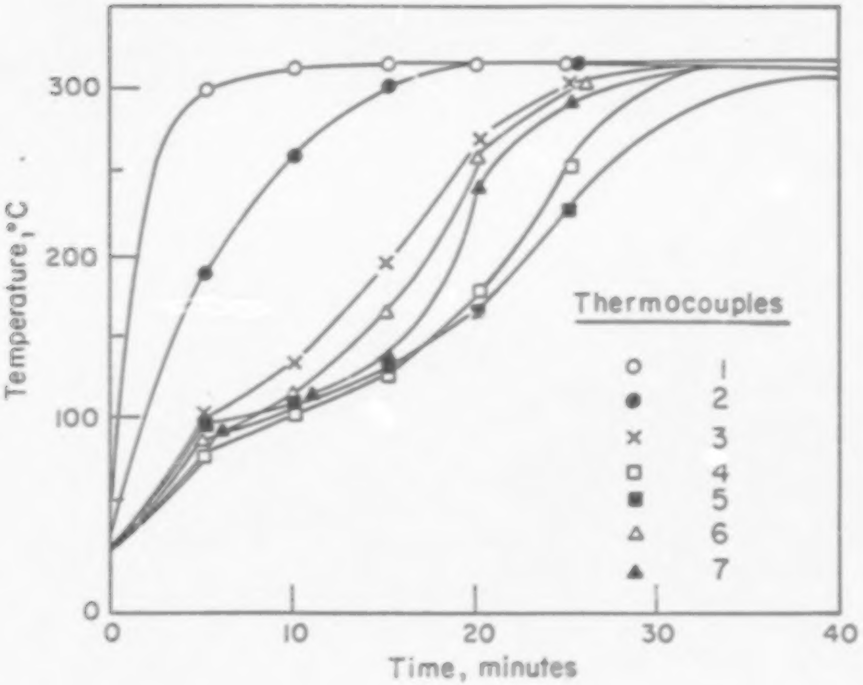

Figure 16. Thermocouple readings for drying at 300°C and 34.0 m^3/hr flow rate.

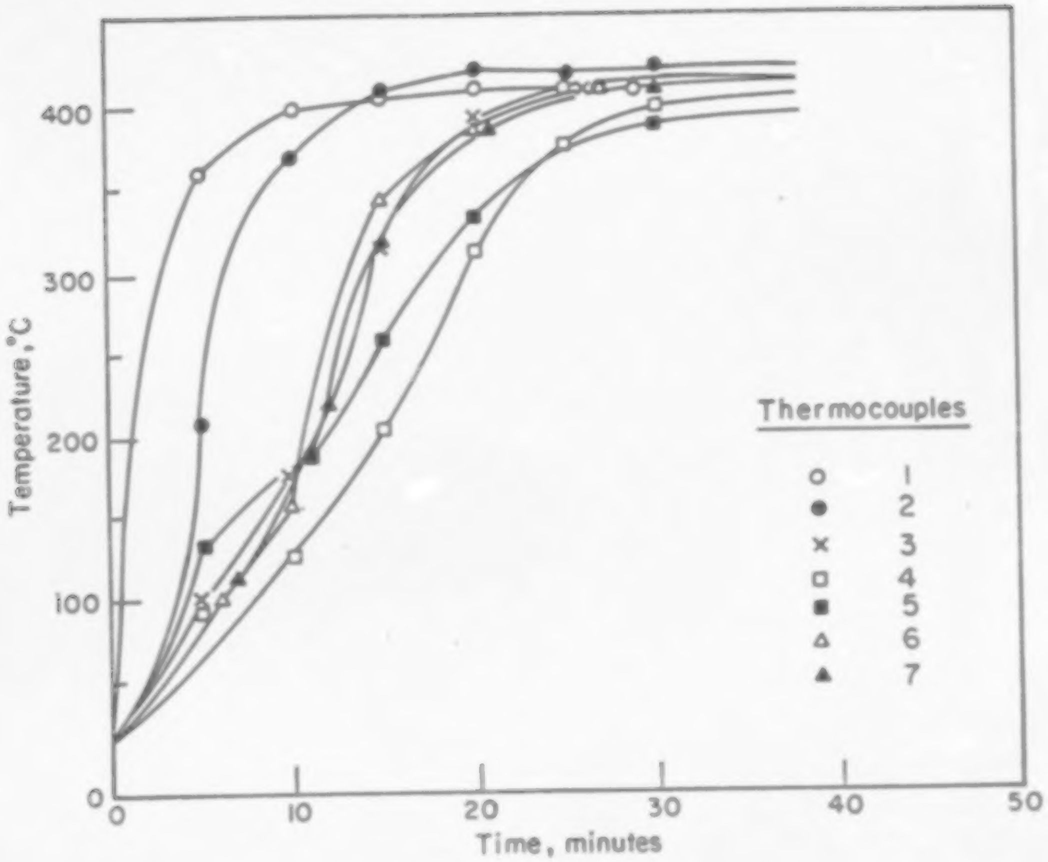

Figure 17. Thermocouple readings for drying at 400°C and 45.3 m^3/hr flor rate.

TABLE 15. AVERAGE COMPRESSIVE STRENGTH OF DRIED AND PREHEATED MS-11 PELLETS

	Drying tests			Preheating tests				
Temperature (°C)	300	300	400	300	600	600	600	800
Flow rate (m^3/hr)	36.1	45.8	46.2	24.8	15.6	21.2	24.8	24.8
Load (N)	123.5	124.5	90.4	109.8	80.4	53.9	81.3	266.7
Standard deviation	23.5	18.6	11.7	30.4	15.6	24.3	15.6	55.8
Strength ($x10^4$ Pa)	78.4	76.4	54.9	67.6	47.0	30.4	47.0	154.9

Preheating Tests

Preheating tests were conducted on MS-11 pellets which had been predried at 100°C in an oven drier. Pellet samples from several lots were combined and evaluated. The preheating test consisted of bringing the preheater to a desired temperature for a given flow rate, inserting the basket full of pellets into the preheating tube, and monitoring the temperatures over the 2 hour test period.

The preheating tests were run at 300°C and 24.8 m^3/hr flow rate, 600°C and 15.6 m^3/hr, 600°C and 21.2 m^3/hr, 600°C and 24.8 m^3/hr, and at 800°C and 24.8 m^3/hr. Thermocouple temperature curves for these tests are shown in Figures 18 through 22. The air and gas flows were measured by water-filled U-tube manometers in the burner supply lines. The pressure drop across the bed of pellets was measured with a manometer. The CO_2 measurements were made with a Fyrite apparatus. The strength test results for samples of preheated pellets are presented in Table 15. Again the strength results appear consistent with those obtained in the cup preheater. As shown before, the strength increases at 800°C.

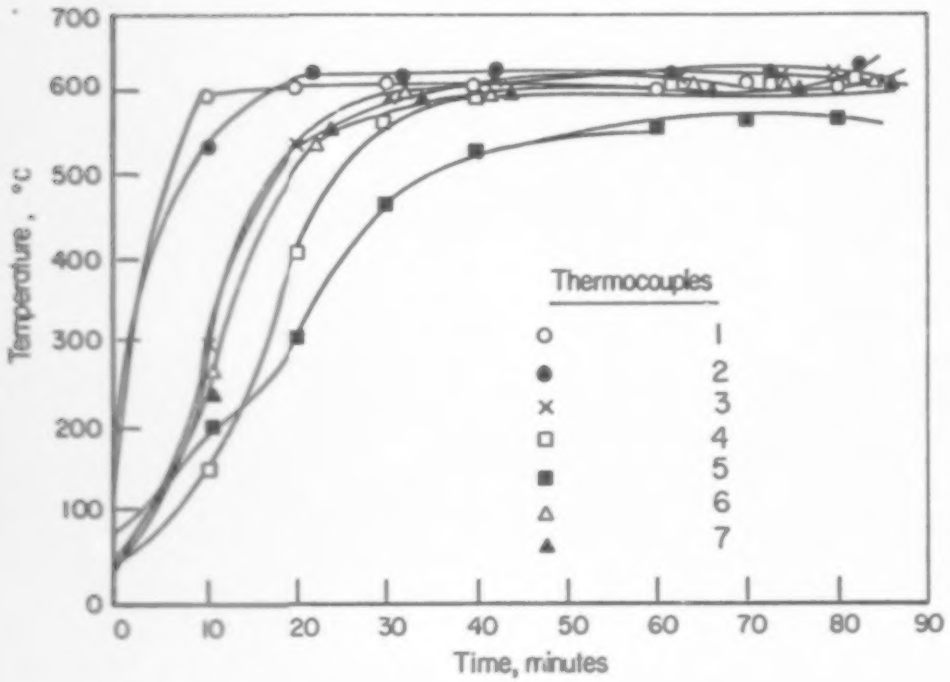

Figure 18. Preheater thermocouple readings for 600°C and 24.8 m^3/hr flow rate.

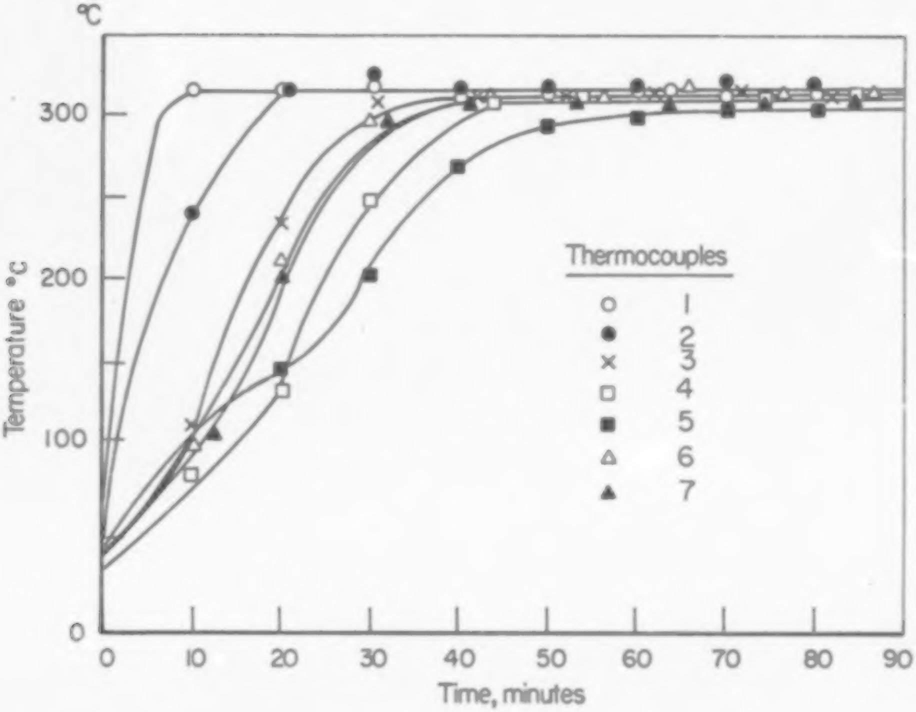

Figure 19. Preheater thermocouple readings for 300°C and 24.8 m^3/hr flow rate.

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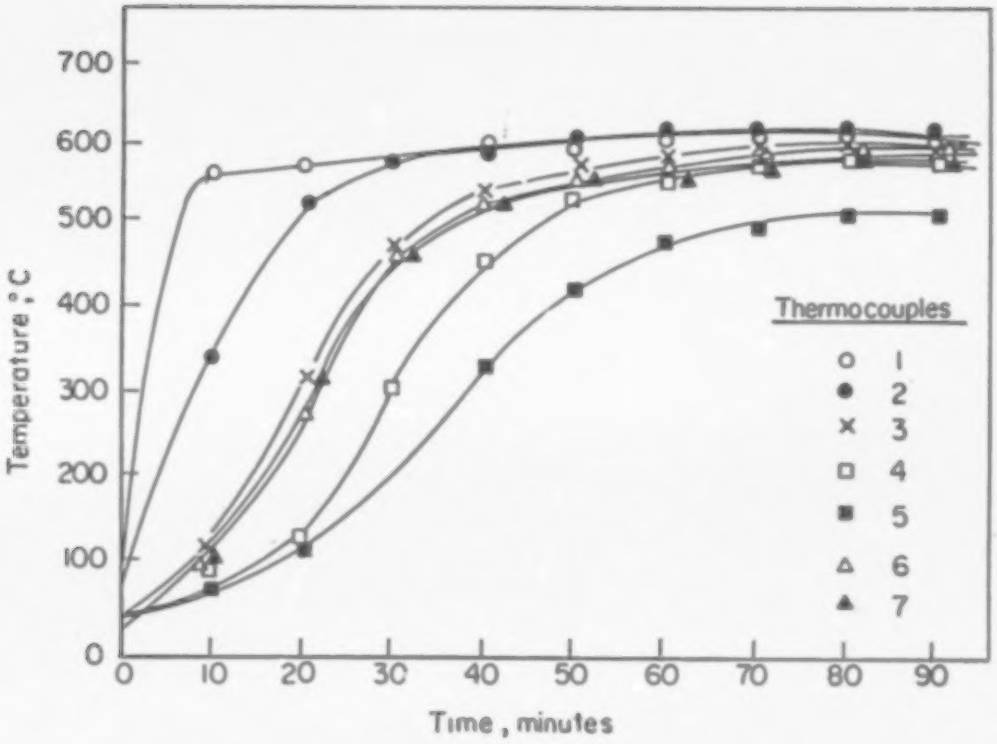

Figure 20. Preheater thermocouple readings for 600°C and 15.6 m^3/hr flow rate.

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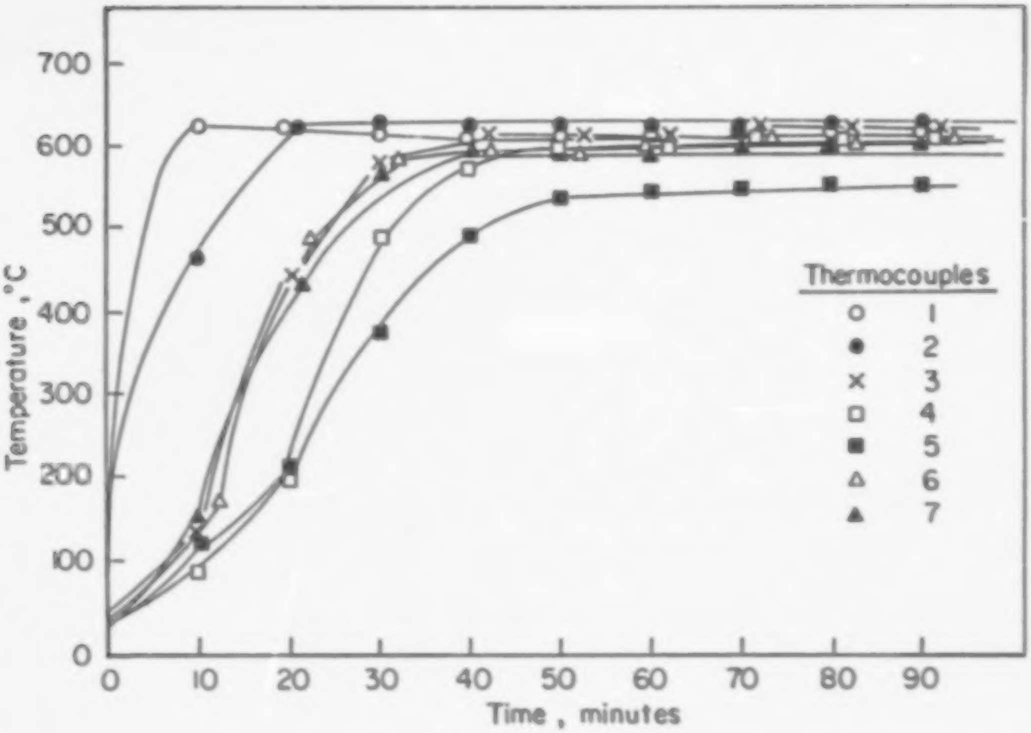

Figure 21. Preheater thermocouple readings for 600°C and 21.2 m^3/hr flow rate.

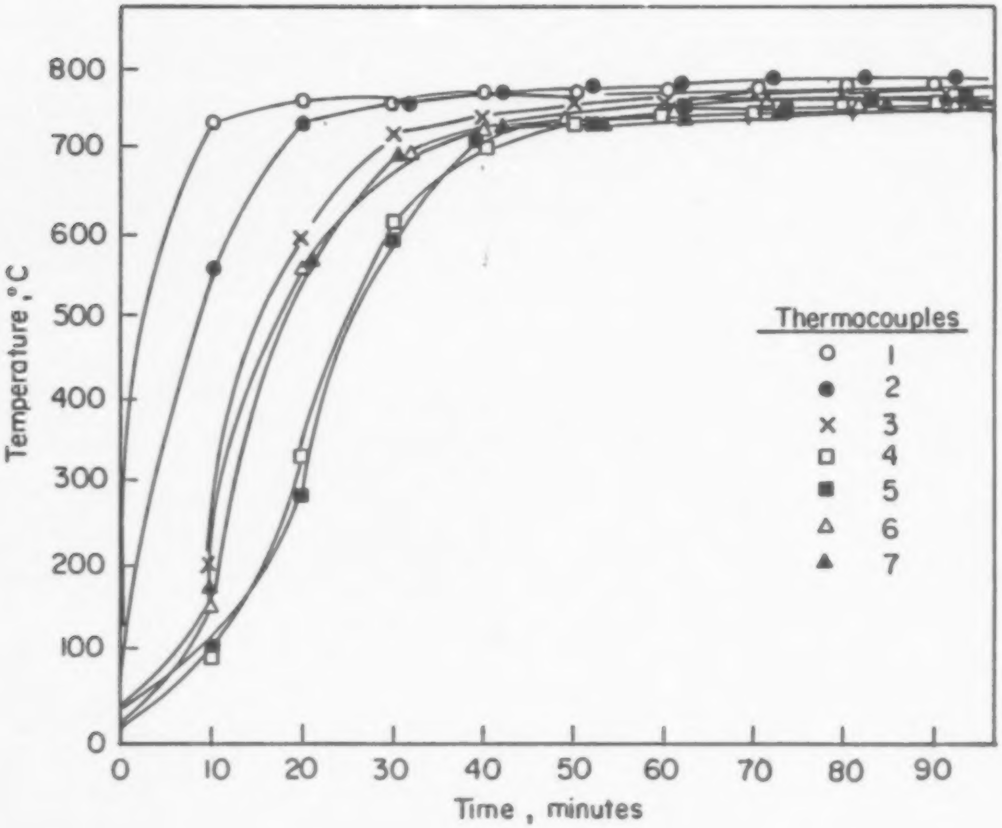

Figure 22. Preheater thermocouple readings for 800°C and 24.8 m^3/hr flow rate.

Hot Load Tests

Hot load tests were conducted for the design of the Phase II preheater. A high temperature creep furnace was modified for hot load strength tests on small beds of pellets. A cylindrical alumina crucible with a diameter of 8.7 cm was filled with an approximate 13 cm column of pellets. A plug of castable refractory was made to distribute the load more uniformly over the column of pellets. An X-Y recorder was connected such that temperature and load or deformation could be recorded.

Rough calculations indicated that a maximum load of 24 kPa (5 psi) would exist on pellets in the proposed pilot plant preheater. Pellets were reported in the Columbia Gas moving-bed tests to have strengths as low as 29 kPa after being preheated to temperatures above 500°C. In these tests, pellets have an overburden of some 454 kg. The calculated load, assuming it was distributed uniformly over the shaft area was about 27 kPa (4 psi). For a 1.4 cm diameter pellet, the load was nearly 4 N under the Columbia Gas test conditions and approximately 5 N for conditions expected in the pilot plant.

The entire pellet load in the shaft is not straight down, but tends to distribute itself much like materials in a pile, with the shaft walls carrying a significant portion of the load. Therefore, the load on pellets at the bottom of the shaft is less than that calculated as the maximum load.

Figure 23 shows the deformation resulting when dried pellets from the MS-11 batch responded to loads of 68 and 103 kPa. Deformation of the pellets occurred as low as 620°C and increased rapidly above 700°C until fracture occurred. Before fracturing, minor deformation of the hot pellets occurred, with little or no sticking together of the pellets.

Figure 24 indicates that pellets were stronger at typical preheating temperatures than at room temperature. Although the hot MS-11 pellets appeared to have a strength maximum of nearly 34 kPa (50 psi), it must be noted that some mechanical adhesion of pellets in the crucibles and crushing of the top layer of pellets indicated that some of the applied load was transferred to the crucible walls rather than to the pellet bed.

Thermogravimetric Prereaction Study

Soda-lime pellets from compositions MS-6, MS-7, MS-8, and MS-11 were tested for degree of prereaction at 800°C by thermogravimetric analysis. The degree of prereaction at 800°C was indicated by the amount of pellet weight loss attributable to loss of carbon dioxide. The test required using a single pellet approximately 1.3 cm in diameter, 1 gram in weight, in a furnace heating at 10°C per minute. The weight of the pellet as a function

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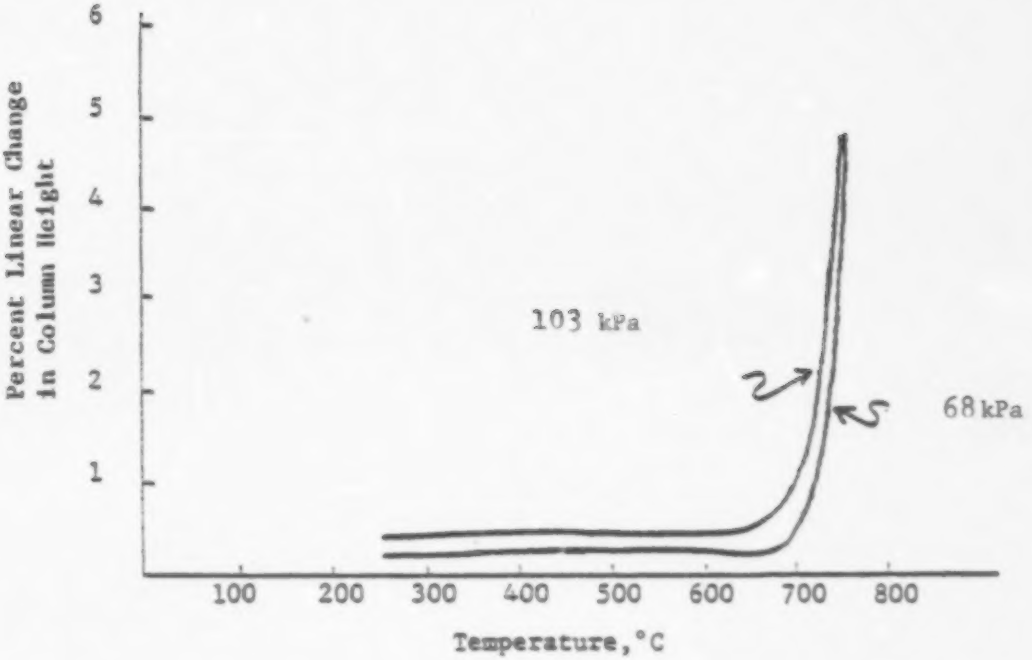

Figure 23. Deformation of MS-11 pellets under 68 kPa and 103 kPa loads: heating rate 350°C/hr.

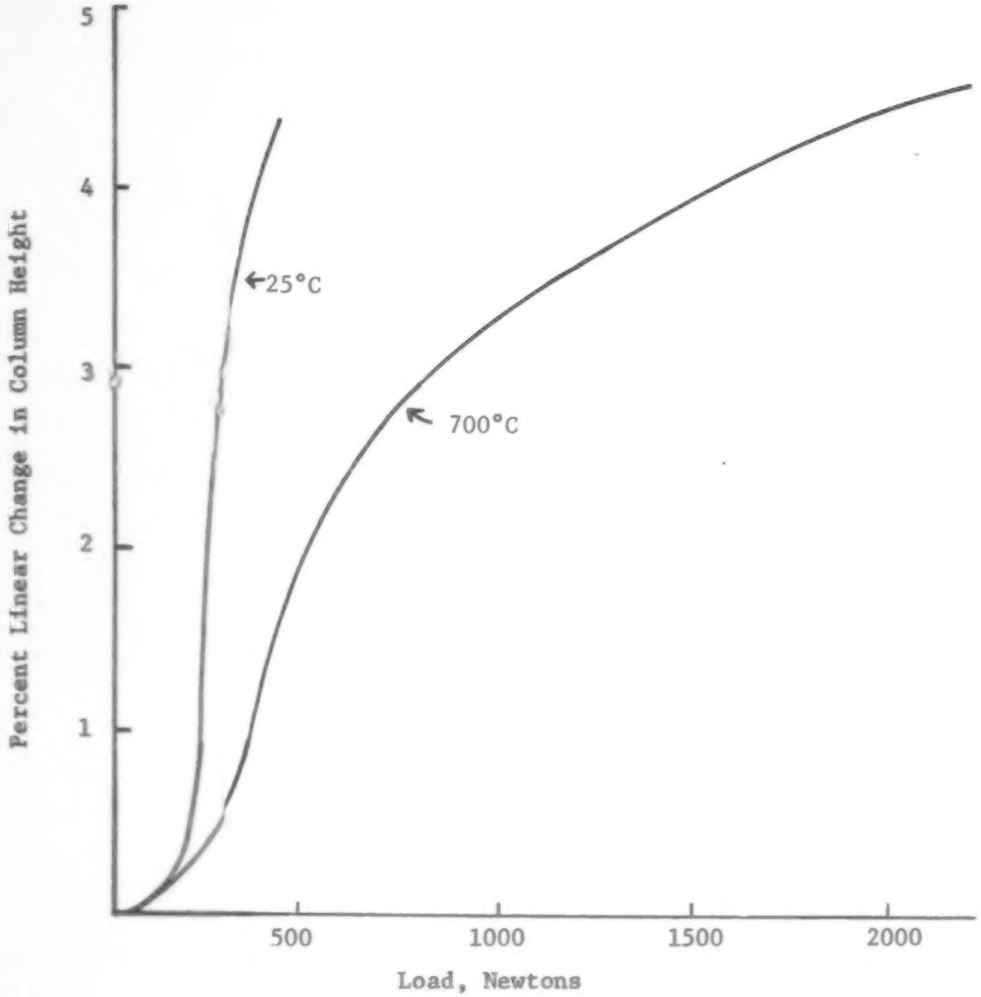

Figure 24. Load versus deformation for MS-11 pellets at 25°C and 700°C.

of temperature was continuously monitored by a strip chart. It was found that the weight of the pellet decreases as the carbonates decompose to carbon dioxide and escape from the pellet. In order to better simulate the combustion atmosphere pellets will experience if heated with waste gases from a glass furnace, the tests were run in an atmosphere of 90% nitrogen and 10% carbon dioxide.

The weight loss observed in these studies was believed to come from the carbon dioxide of the limestone, the carbon dioxide of the sodium carbonate, and the combustion of the carbocite. Sodium sulfate in the pellets should release sulfur dioxide below approximately 1200°C. Water loss from incompletely dried pellets and water loss from the hydration in the burned dolomite and sodium carbonate, should be observed on heating between 100°C and 200°C.

The results of the prereaction study are in Table 16. A typical thermogravimetric analysis (TGA) curve is shown in Figure 25. The data expresses the weight loss of each pellet as a percentage of the pellet's 200°C weight (after water loss) for the given time or temperature interval. Pellets were heated from room temperature to 800°C at 10°C per minute, then held at 800°C for three hours. Pellets MS-6 and MS-7 were run once each. Pellets MS-8 and MS-11 were run twice each to check the repeatability of the test. Single runs were also made on MS-11 pellets which had been preheated to 600°C and 800°C. Note that the 800°C preheated MS-11 pellet showed a weight gain of 0.4% on reheating. Weight loss may be from the loss of carbon dioxide from limestones, sodium carbonate, and carbocite calculated from the batch assuming total loss. It is not possible to predict the loss from pellets which have been preheated to 600°C or 800°C because the extent of prereaction is unknown.

It is obvious that the water loss observed up to 200°C is highly variable. The pellets started the test with different moisture contents. It is also clear that the repeatability of pellets MS-8 and MS-11 was not high. Because the thermogravimetric instrument is checked frequently against standard materials and found to be highly repeatable, the source of the variablility probably lies in the physical and chemical properties of the individual pellets tested. The 800°C preheated MS-11 pellet experiences a slight, and inexplicable, weight gain on heating. The 600°C preheated MS-11 pellet shows an additional small weight loss on heating to 800°C because it was not fully reacted at 600°C.

Roughly half of the total possible weight loss was observed in these tests. To release the remaining carbon dioxide requires higher, but unexplored, temperatures. The rate of weight loss at 800°C diminishes with time so that after three hours nearly all of the carbon dioxide was released. As indicated by the 800°C

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TABLE 16. TGA WEIGHT LOSS DATA

Percent weight loss

Interval	MS-6	MS-7	MS-8	MS-8	MS-11	MS-11	Preheated 800°C MS-11	Preheated 600°C MS-11
22°-200°C	3.6	8.6	4.2	3.0	0.2	0.1	0.1	
200°-800°C	3.7	3.2	3.7	3.1	1.9	0.4	1.8	-0.4
800°C,1st hr	4.2	2.3	2.4	2.5	1.9	1.3	3.1	
800°C,2nd hr	0.8	0.6	1.0	0.6	0.5	0.6	0.8	
800°C,3rd hr	0.5	0.4	0.4	0.3	0.5	0.5	0.6	
Total loss from 200°C	9.2	6.5	7.5	6.5	4.8	2.8	6.3	-0.4
Max possible CO_2 loss	11.5	12.5	11.5	11.5	12.5		12.5	

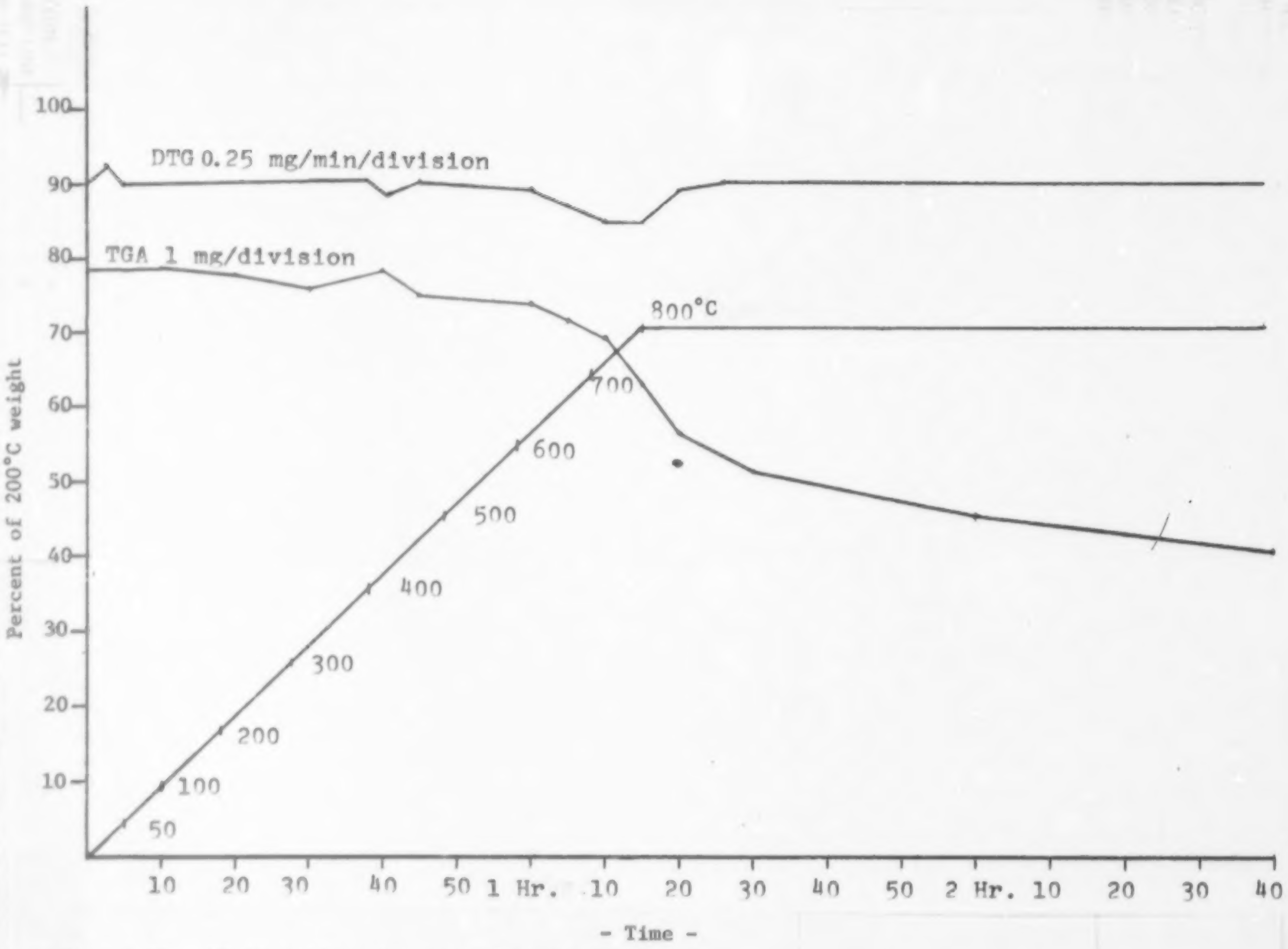

Figure 25. MS-11 pellet thermogravimetric analysis.

preheated MS-11 pellets, the carbon dioxide loss was not reversed by cooling the pellets back to room temperature.

Borosilicate Pellet Drying Tests

As previously discussed, borosilicate pellets were produced from various raw material combinations. A determination of whether or not the pellets could survive drying (approximately 100°C) and preheating (approximately 700°C) was the next logical step. The following describes the results.

Wet pellets containing 5 mol borax exhibited the poorest drying and preheating behavior. When heated to 100°C for 20 minutes, each pellet developed an elastic skin which contained a soggy core of moist raw materials. Apparently the increase in water solubility of boric acid and borax with increasing temperature caused the hot wet pellets to weaken. Air drying for 24 hours circumvented the problem. With 5 mol borax, it is known that the water of hydration is driven off gradually between 135°C and 500°C. It is also known that exfoliation, an approximate seven-fold volume increase in the 5 mol borax grains, accompanies the water release. This was observed during the pellet preheating. The large increase in borax grain volume seriously weakened the pellets while opening up large voids where the water vapor escaped.

Wet pellets containing anhydrous borax were successfully dried in air for 24 hours or in a 100°C oven for 30 minutes. Once dry they may be preheated to 700°C with only a slight amount of pellet expansion and cracking as a result of boric acid dehydration. At 700°C the pellets were hard, dense, and non-sticking.

Within the qualitative observations of these tests, no drying behavior differences were seen using Oklahoma, Berkeley, and 200 mesh sands.

POLLUTION CAPTURE

One of the most significant factors of the preheating concept is its potential capability to reduce or eliminate pollutant emissions from a glass melting furnace. Laboratory experiments were, therefore, conducted to predict the capability of the pilot system to capture SO_x and particulate emissions from the glass melting furnace. This section discusses the results of those studies.

SO_2 Capture

Measuring Equipment--

The SO_2 concentrations in the incoming and outgoing gas streams were measured with a gas chromatograph operating on a flame photometric principle. This instrument printed out SO_2

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concentrations in parts per million (ppm). Daily instrument standardizations were performed with a Linde SO_2 standard gas mixture. Cross checks were also performed with Matheson H_2S, COS, and methyl mercaptan standard gas mixtures. Under the above conditions, the SO_2 retention time was 2.14 minutes. Sensitivity for SO_2 was nominally about 170,000 peak counts/0.2 cc injection of 146 ppm SO_2 standard. Equipment specifications are shown in Table B-12 in Appendix B.

SO_2 Test Operating Procedures--

Concurrent with each of the preheat runs in the static bed preheater, tests were conducted on SO_2 removal. The SO_2 capture tests consisted of monitoring SO_2 concentration in the combustion gases flowing into and out of the basket full of pellets in the preheater. Samples of the gas stream in the preheater were pulled through a glass sampling bottle by vacuum, the bottle was closed off, and then taken to the testing laboratory where a sample was withdrawn with a syringe and injected into the gas chromatograph. The gas stream was sampled before the SO_2 was turned on. After the SO_2 was introduced as a gas into the combustion air line, one sample was taken of the gas stream ahead of the basket, while samples were taken downstream of the basket periodically during the 2 hour test period. The CO_2 content of the gas stream ahead of the basket was also measured several times during the tests with a Fyrite apparatus (Fyrite = chemical absorption in liquids). The SO_2 capture tests were conducted concurrently with the preheating tests.

Test Results--

The results obtained in the SO_2 capture tests are given in Appendix B, Tables B-13 to B-17. Tests were made at pellet bed temperatures of approximately 300, 600, and 800°C and at three gas flow rates for the 600°C runs. The percent SO_2 capture is plotted in Figure 26 as a function of test time for each of the three temperatures and in Figure 27 for each of the three flow rates at 600°C.

In figure 26, the SO_2 capture increases at higher temperatures, but even capture at 300°C is significant. The SO_2 capture decreases with test time as would be expected in a static bed. The data also show some scatter due to the intermittant sampling periods, but overall trends are obvious.

Figure 27 shows that SO_2 capture is a function of gas flow rate at a particular temperature. However, there appears to be an optimum flow rate under the static bed conditions. The capture rate was lowest for the low flow rates and highest for the intermediate flow rate. This result is consistent with particulate capture in packed beds[3], although this may be coincidental.

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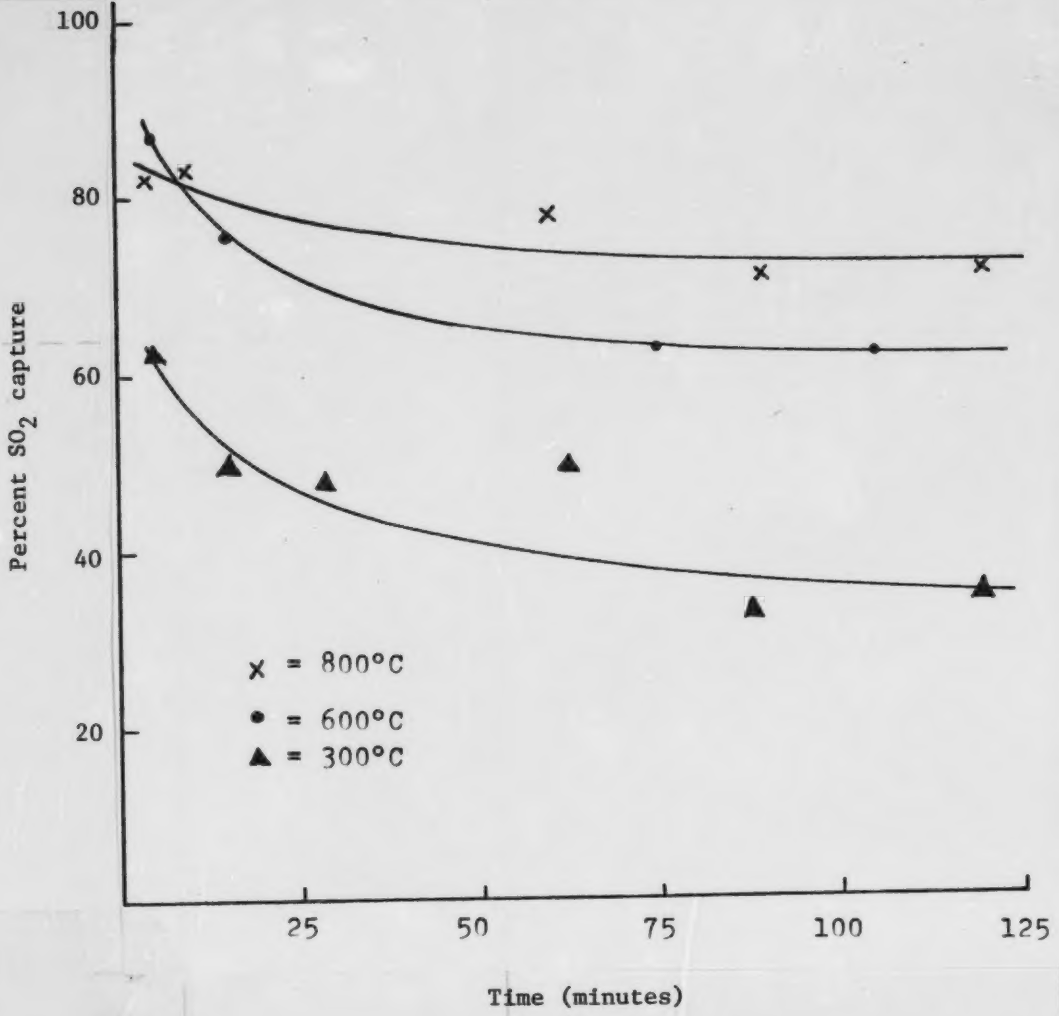

Figure 26. SO_2 capture at different temperatures with a flow rate of $26.2M^3$/hr (925 ft^3/hr)

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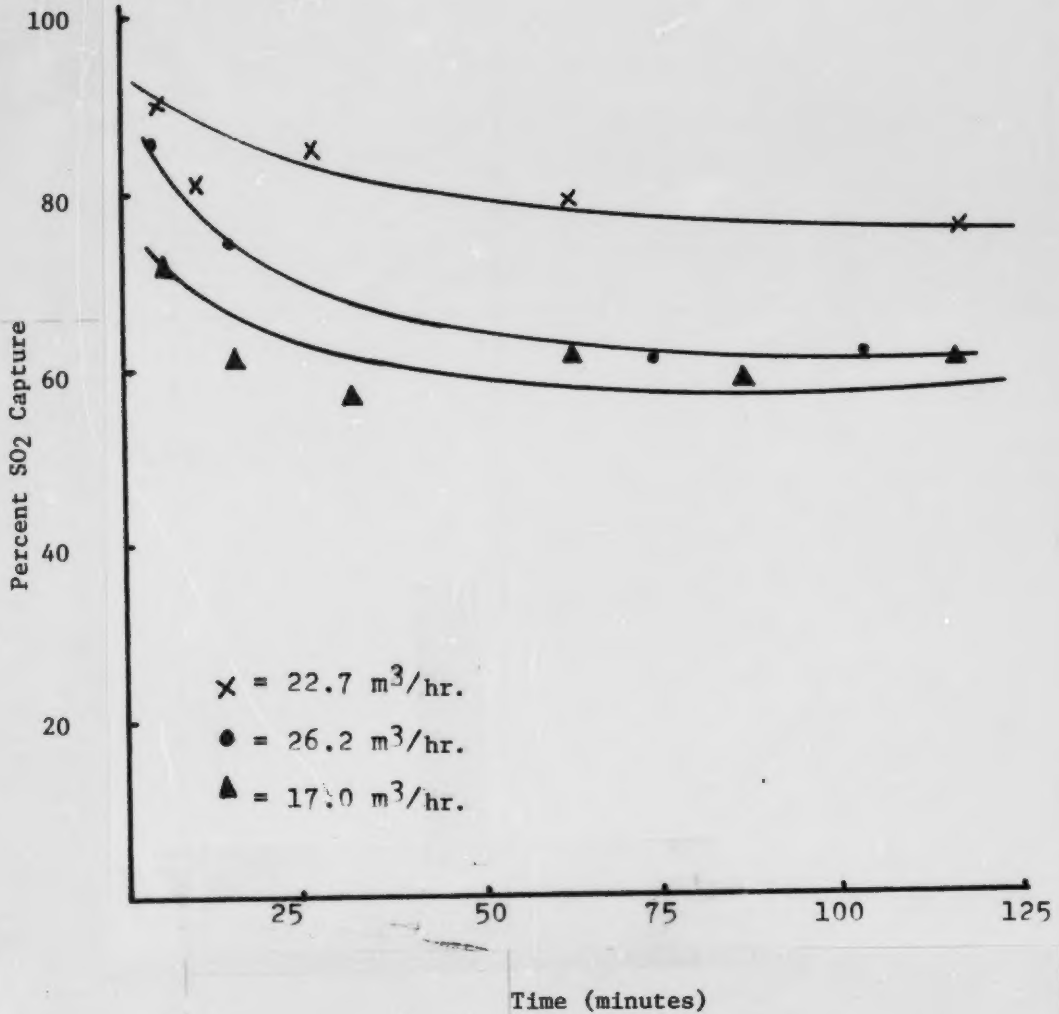

Figure 27. SO_2 capture at 600°C for different flow rates.

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Material	Flow	Opening	% Above Theoretical
Pellets	645 kg/hr	19 cm	4.3 (8° slope on trough)
8% Wet Batch	754 kg/hr	19 cm	5.9 (23° slope on trough)
Dry Batch	827 kg/hr	15 cm	4.5 (15° slope on trough)

The charging rates expected with normal furnace/melt resistance to charging (correlated to the batch pile contours at the trough slope angles indicated) are given below. For these calculations the charger was set at minimum stroke (3 cm) and speed (10 strokes/min), and the pusher bar was 7.6 cm high x 38 cm wide. The charging rates are reported as kg/hr.

Materials	Opening Height		
	19 cm	15 cm	11 cm
Pellets	645 (8°)	544 (12°)	416
Pellets & 20% Cullet	--	--	465
Wet Batch (8% water)	721 (20°)	--	495
Wet Batch (8% water) & 20% Cullet	--	--	541
Dry Batch	--	827 (15°)	509

The preceding indicates that the 11.5 cm opening height appears preferable to achieve the low flow rates desired (226 - 635 kg/hr).

The actual throughputs of the system under conditions of restricted (11.5 cm high) opening and correlated through-simulated batch pile flow resistance from furnace/melt conditions became:

Pellets _ $\frac{416}{618}$ = 67.3% of theoretical flow (resistance free)
Wet Batch (8%) _ $\frac{495}{712}$ = 69.5% of theoretical flow (resistance free)
Dry Batch _ $\frac{509}{792}$ = 64.3% of theoretical flow (resistance free)

Assuming a linear relationship of throughput to charger pusher bar displacement volume and speed, it is conceivable that

No evaluation of the capture mechanism was done. Overall, these tests definitely show the ability of preheated soda-lime glass batch pellets to remove SO_2 from combustion gases.

Na_2SO_4 Particulate Capture

Measuring Equipment--

Pellet samples were analyzed for total sulfur on a Leco IR-32 Infrared Sulfur Determinator. Specifications for this equipment are given in Table B-23 Appendix B.

Particulate Test Operating Procedures--

Sodium sulfate was ground in a ball mill to pass US series 200 mesh. The diameter of the particulates ranged from 1 to 35 µm with a mean particle radius of 10 µm. The size distribution is shown in Figure 28. Particulate capture tests were run in a static bed preheater. Figure 29 shows the particulate injector system. A North American Gas Aspirator was modified and fitted with a funnel to aspirate the sodium sulfate particulate and inject it into the combustion gas stream below the pellet bed. During debugging of the system, only a trace of the particulate injected into the gas stream settled out below the pellet bed. However, there was significant particulate capture observed on the walls of the combustion gas pipe and on the screen bottom of the preheater pellet basket. The amount of material collected by the walls and the screen below the pellets is not known and was not reflected in the calculations of percent particulate capture. The results, therefore, are considered conservative.

Test Results--

Three sodium sulfate particulate capture tests were run at 300, 500, and 650°C. Fifty grams of sodium sulfate powder (radius 1-35 µm) was inspirated into a hot gas stream at 1 gram per minute. The gas flow was 28 m^3/hr and was passed upward through a (3.2 kg) bed of pellets. The pellet bed diameter was 14.8 cm. In the first analysis, individual pellets were taken from each 3.2 kg sample and analyzed for SO_3 content. Sodium sulfate capture was calculated as a percent by weight of total particulate input. The results of this analysis are shown in Figure 30 as the "single pellet sample". The scatter in the data was attributed to unrepresentative sampling. Each 3.2 kg sample was ground to pass 40 mesh and riffled down to 5 samples each. The samples were analyzed for SO_3; the percent capture was calculated; and the percent capture was averaged for each of the samples. Results of this analysis are also shown in Figure 30 as the "average of whole sample". The average capture ranged from 19% at 300°C to 29% at 650°C.

Particulate Capture Scale-up--

Semi-empirical relationships have been developed to predict collection efficiencies of granular bed filters (5). Four mechanisms

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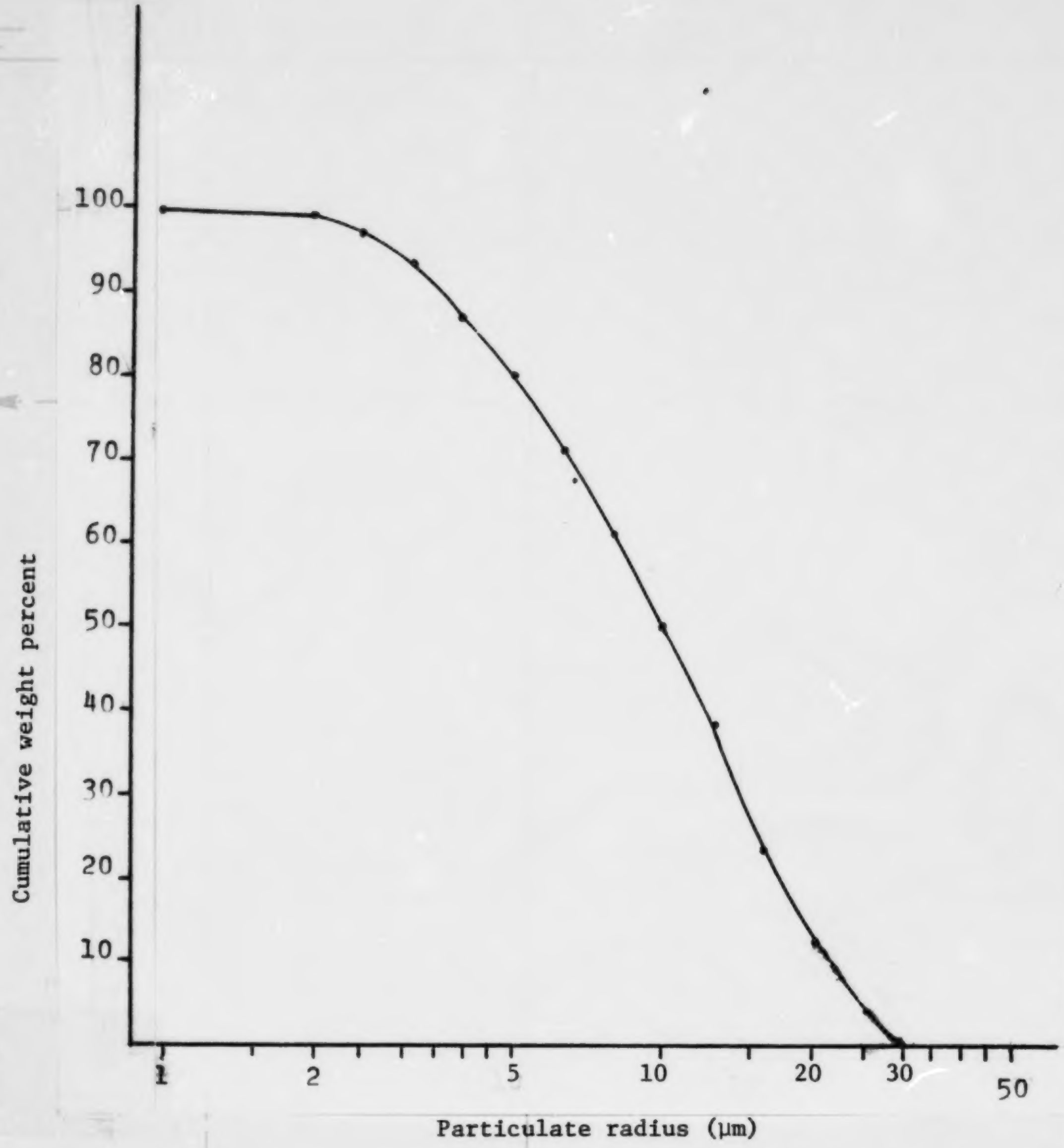

Figure 28. Sodium sulfate particulate size distribution.

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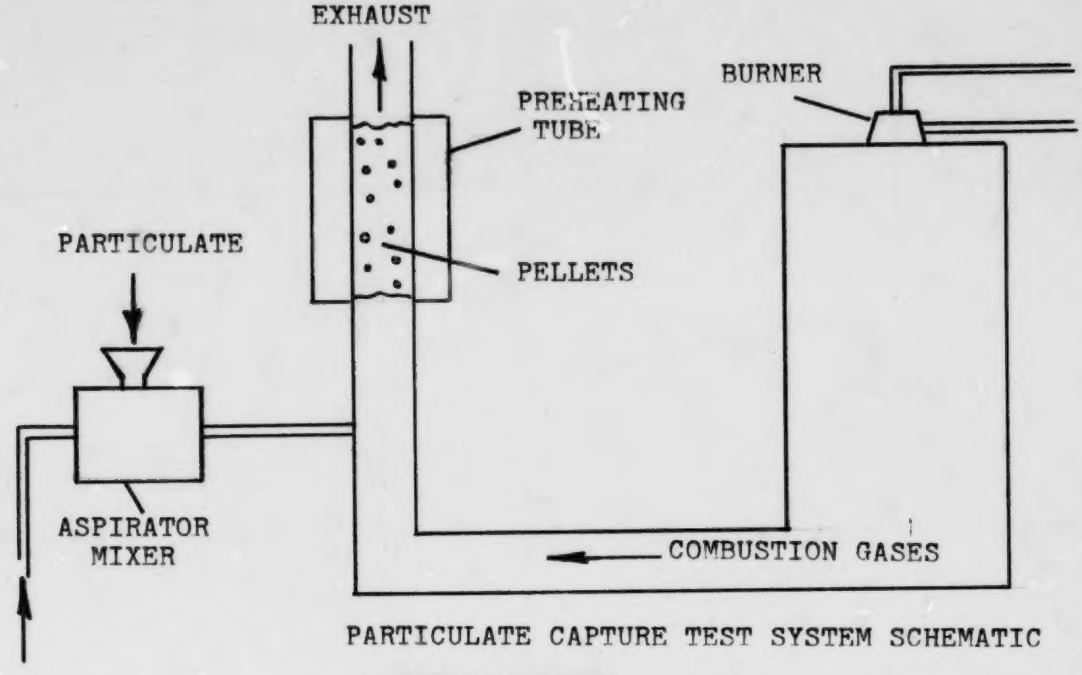
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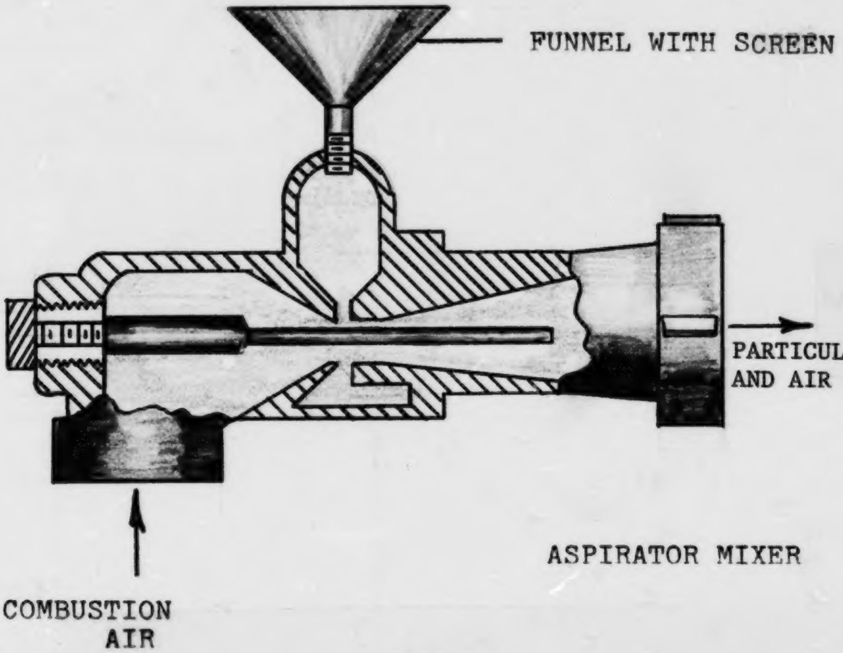
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ASPIRATOR MIXER

Figure 29. Particulate injection system.

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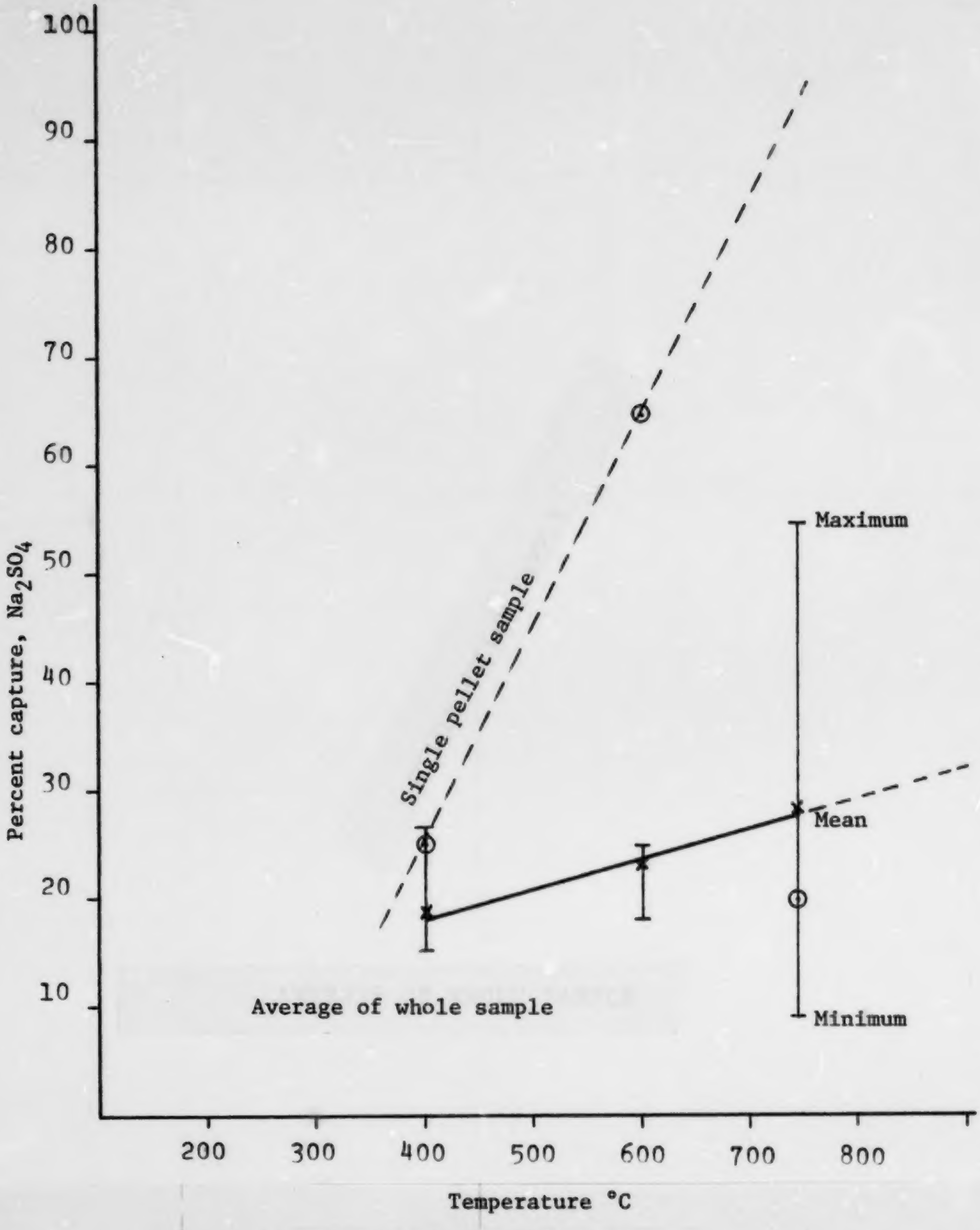

Figure 30. Sodium sulfate capture data.

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were taken into account: diffusion, interception, inertial collection, and gravitational settling. The overall bed efficiency is given by:

$$E = 1 - \exp(-kE_{\beta i}L\beta/R)$$

where

E = overall filter efficiency.

$E_{\beta i}$ = single sphere collection efficiency by mechanism i with correction for interference effects from neighboring spheres packed with density β; the total single sphere collection efficiency may be noted as $E_{\beta T}$ where $E_{\beta T} = \Sigma_i E_{\beta i}$.

k = empirical constant = 3.75.

β = packing density for spherical collectors.

L = packed bed filter thickness.

R = individual spherical collector radius.

$E_{\beta T} = E_D + E_R + E_I + E_G$

$E_D = 8\,Pe^{-1} + 2.308\,Re^{1/8}\,Pe^{-5/8}$ (diffusion).

$E_R = 1.45\,I_R^2$ (interception).

$E_I = k_I\,Stk$ (inertial collection).

$E_G = V_s/U$ (settling).

Parameters used to calculate the single sphere collection efficiencies are shown in Table 17. Values are given for parameters held constant in this analysis. The three parameters evaluated were the temperature, T; particle radius, r; and packed bed length, L. The parameters D, I_R, Pe, Re, Stk, V_s, and μ are dependent on r and/or T. Single sphere collection efficiencies were calculated for 300°C and 800°C and a range of particle radii from 0.5 to 50 µm. These are shown in Table 18. The total single sphere collection efficiency is relatively insensitive to temperature. Changing from 300°C to 800°C decreases $E_{\beta T}$ by 20 to 35% depending on the particle radius. The results of the 800°C case are plotted in Figure 31. These graphs indicate that, as an approximation, the single sphere collection efficiencies (E_R, E_I, E_G) increase as the particle radius squared as a result of interception, inertial collection, and settling. The single sphere collection (E_R, E_I, and E_G, respectively) efficiencies increase approximately as the reciprocal of the particle radius as a result of diffusion (E_D). Inertial collection and gravitational settling are the dominant mechanisms for capture of particles with radii larger than 0.5 µm. In this particle size range, capture will increase with particle size. For particles smaller than 0.2 µm diffusion becomes the dominant mechanism and capture increases with smaller particle size. This shift from inertial dominated capture to diffusion dominated capture produces a minimum total collection efficiency for particles with a radius near 0.2 µm (5).

TABLE 17. PARTICULATE CAPTURE PARAMETERS

C = Cunningham correction factor (~1 in our range)
D = particle diffusivity
I_R = interception parameter, r/R
Pe = Peclet number, $2RU/D$
R = collector radius = 0.64 cm
Re = collector Reynolds number, $2RU\rho_F/\mu$
Stk = Stokes number, $2\rho_p r^2 UC/9\mu R$
U = mainstream reference velocity = 47 cm/sec
V_s = particle settling velocity
β = packing density = 0.6
μ = coefficient of viscosity
ρ_F = gas density = 1.3 kg/m^3
ρ_p = particle density = 2680 kg/m^3

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TABLE 18. SINGLE SPHERE COLLECTION EFFICIENCIES

T(°C)	r(m)	Pe	Re	E_Dx10^6	E_Rx10^6	E_I	E_Gx10^3	E_{bT}
800	0.5	1.86×10^7		132	0.009	8.41×10^{-4}	0.112	0.0011
	1	4.19×10^7		79.4	0.036	3.36×10^{-3}	0.446	0.0039
	2	9.01×10^7		49.2	0.144	1.35×10^{-2}	01.7	0.015
	5	2.0×10^8	255	29.9	0.900	8.41×10^{-2}	10.3	0.094
	10	4.0×10^8		19.4	3.60	0.366	39	0.38
	20	8.38×10^8		12.2	14.4	1.35	150	1.5
	50	2.08×10^9		6.90	90	8.4	850	8.5
300	0.5	5.33×10^7		64.9	0.009	1.27×10^{-3}	0.099	0.0014
	1	1.20×10^8		39.0	0.036	5.07×10^{-3}	0.394	0.0055
	2	2.58×10^8		24.2	0.144	2.04×10^{-2}	1.5	0.022
	5	5.73×10^8	169	14.7	0.900	0.127	9.1	0.14
	10	1.15×10^9		9.5	3.60	0.507	34	0.54
	20	2.40×10^9		6.0	14.4	2.04	130	2.2
	50	5.96×10^9		3.4	90	12.7	750	13

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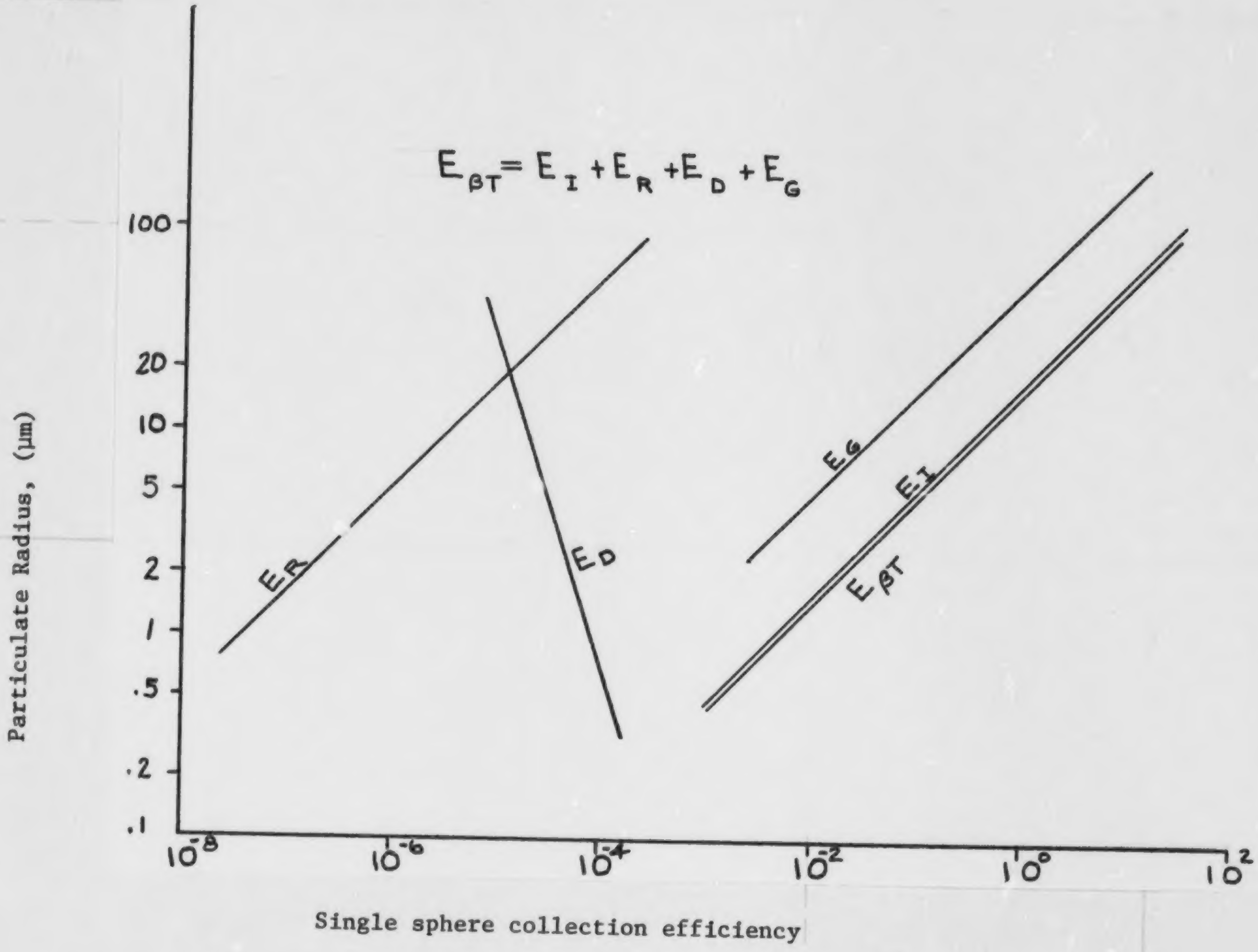

Figure 31. Particulate collection efficiencies for various mechanisms.

Pellet bed collection efficiency is plotted in Figure 32 for both a 17.8 cm and a 305 cm bed for a range of particle radii from 0.5 to 50 µm. The 17.8 cm case represents the bench scale preheater while the 305 cm case represents the pilot plant preheater. These curves show that the model predicts greater than 98% capture for particles larger than 4 µm in the 17.8 cm bed and for particles larger than 1 µm in the 305 cm bed. This illustrates the trade off between smaller particulate size and larger pellet bed.

Bench scale results showed capture that was less than one third that predicted by the model for the mean particle radius of 10 mm. Because the particulates captured by the wall are not taken into account, it is believed that the actual capture is higher than measured. Therefore, it is believed reasonable to expect that one third of the particulates in the 0.5 mm range can be captured in the pilot plant preheater.

Determination of Reduction in NO_x Emission

A typical $60 m^2$ regenerative furnace, with a 136×10^3 kg/day output, requires 43×10^9 J/hr of fuel. In addition, a 50°C reduction in furnace temperature results in a 15% reduction in fuel usage.

Table 19 summarizes the energy and combustion product quantity as a function of temperature as follows:

TABLE 19. FURNACE ENERGY, AND COMBUSTION PRODUCTS

Bridgewall temp (°C)	Energy (10^9 J/hr)	Combustion products (10^3 kg/day)
1550	72.7	425
1500	63.2	370
1450	54.1	315
1400	44.3	259

Table 20 shows data reported by Arrandale on NO_x emission as a function of temperature (6).

TABLE 20. NO_x Emissions Versus Temperature

Bridgewall temp (°C)	NO_x emission (PPM)
1550	575
1500	230
1450	100
1400	100

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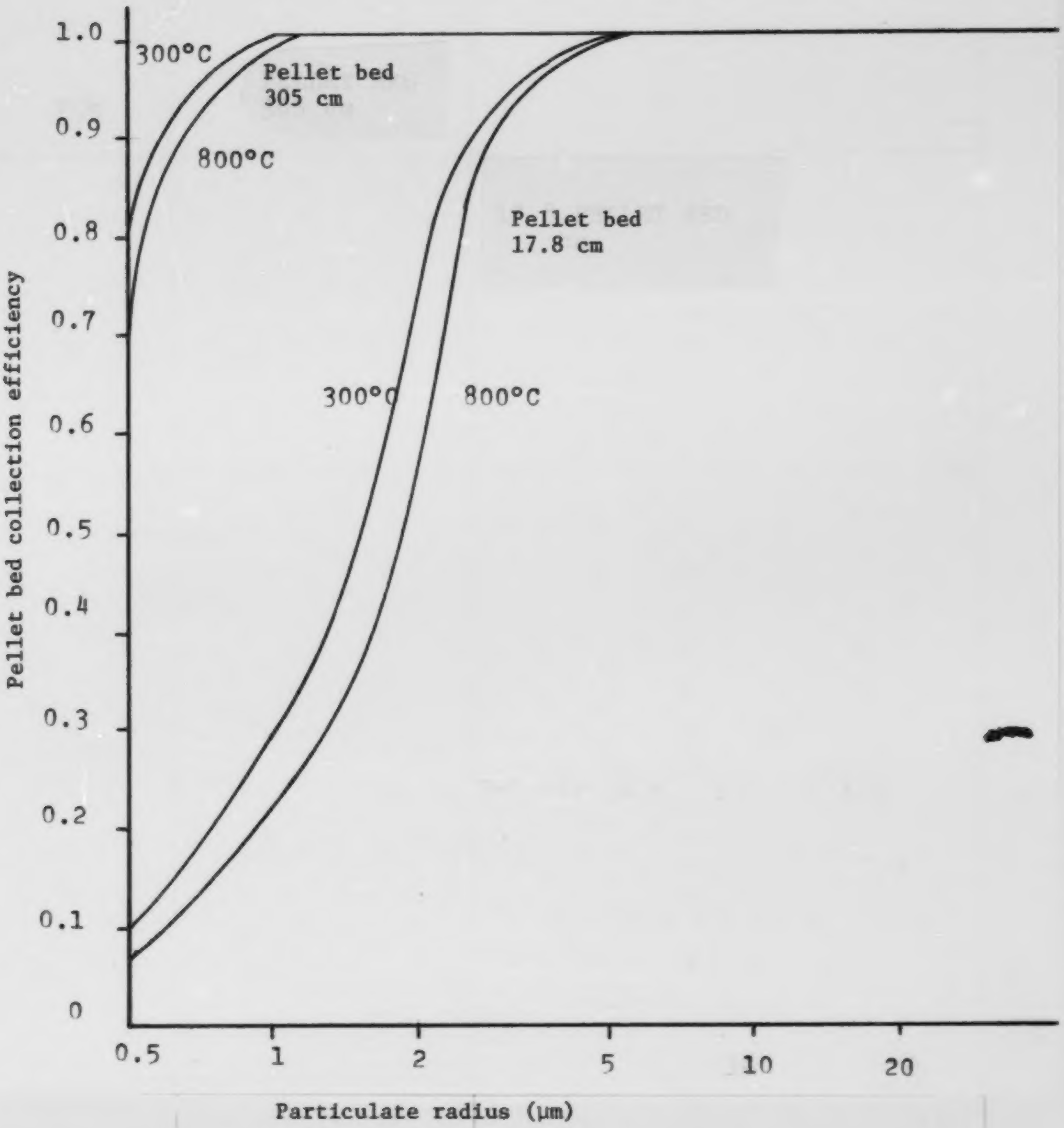

Figure 32. Pellet bed collection efficiency versus particle radius.

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By using this data we can calculate the NO_x emission (kg/day) reflecting the effect of fuel and temperature reduction as follows:

$$\underset{\text{(kg/day)}}{\text{Actual emissions}} = \underset{\text{(kg/day)}}{\text{Comb product}} \times \underset{\text{PPMx}10^{-6}}{NO_x \text{ emission}}$$

We can also calculate the percentage of NO_x emission reduction as a function of temperature.

Table 21 summarizes these results:

TABLE 21. NO_x Emission Reduction

Bridgewall Temp (°C)	Base NO_x kg/day	NO_x with 50°C ΔT kg/day	Percent reduction
1550	245	85	65.0
1500	85	31	63.0
1450	31	26	15.0
1400	26	26	--

HOT TRANSFER

The purpose of these studies were to develop a concept that would allow pellets to flow from the preheater, and then discharge into a mixing chamber where cullet could be added and fed to the furnace.

In order to develop this concept three separate studies were conducted. They included:

1) A sticking test to determine the maximum temperature that pellets could be subjected to without sticking.

2) A thermal analysis of conventional charging equipment to determine the extent of insulation and cooling required to minimize heat losses and yet not exceed sticking temperatures.

3) Cold modeling of loose batch and pellets in a conventional charger to determine flow characteristics and evaluate potential flow blockage problems.

Sticking Behavior of Hot Pellets

Five tests were run to determine the temperatures [illegible]hich pellets begin to stick to each other, "black iron" steel, and kiln lining refractory. A small globar box furnace with a useable interior chamber approximating a 23 cm cube was used in these experiments. The furnace was heated by 12 globars with a maximum power input of 6 kilowatts. From room temperature the furnace reached the temperatures of the experiments (800-870°C) in about 80 minutes.

The pellets were held in a black iron box approximately 15 cm x 7.6 cm x 5 cm deep. Below the pellets was an air cooling chamber 15 cm x 7.6 cm x 2.5 cm deep. One thermocouple contacted the steel bottom of the pellet chamber. Another thermocouple was placed in air, surrounded by pellets. The steel pellet chamber, open at the top, was covered with a piece of refractory brick.

In the first experiment no air cooling was used, the bottom thermocouple failed, but the top thermocouple reached 800°C. Some pellets did deform, however, sticking did not occur, except for a few pellets touching the steel walls closest to the globars. It is believed that the local temperature of these walls exceeded 800°C.

In the second experiment air cooling was used to keep the bottom steel cooler than the bed of pellets. With both thermocouples functioning, the air cooled steel bottom reached 750°C and the pellet bed reached 800°C. Again sticking only occurred on the outer, hotter steel walls.

The third experiment achieved 870°C on the top thermocouple and 800°C on the air cooled bottom. Pellet to pellet sticking did occur during this test, however, pellets did not stick to the 800°C steel. Pellet to refractory sticking was obscured by the thermocouple placement.

In the fourth experiment, without air cooling, both thermocouples reached 850°C. Pellets were carefully placed on the refractory brick to insure useful results. The pellets were found to stick to each other, to steel, and to refractory brick.

The fifth experiment was run at 825°C with weights placed on the refractory brick to produce 34 kPa (5 psi) on a group of pellets. These pellets also stuck to themselves, to steel, and to refractory brick.

In summary, during static heatup and cooldown situations, pellets deform but do not stick at temperatures up to 800°C. Whereas, at 825°C pellets stick to each other, to steel, and to the kiln lining brick.

Thermal Analysis of Batch Charger

Purpose--

Two types of batch charges commonly used by the container industry are GANA and EMHART chargers. The GANA charger fills batch on a free glass surface while the EMHART charger fills batch through its wall. In order to resolve concepts for the Phase II pilot plant plans, and provide a small system with minimizing heat loss, the thermal losses in the GANA and EMHART batch chargers were mathematically modeled using standard designs and differing insulation values.

Technique--

A 2-D thermal conduction computer model was used to study both systems. Figures 33 and 34 show the 2-D layouts used for the GANA and EMHART units. Table 22 lists the material elements and their corresponding thermal conductivities. The heat transfer coefficients used for the external surfaces were those for free convection from a horizontal or vertical surface with an emissivity of 0.95.

TABLE 22.
BATCH CHARGER MATERIALS AND THERMAL CONDUCTIVITIES

Material	°C	k(Joule/hr-m-°C) at T(°C)
Insulation	for T>650	k = -130 + .858 T
	T<650	k = 26 + .622 T
Batch		k = 623 (Cold)
		k = 6,230 (Hot)
		k = 6,230, 62,300, 156,000, 312,000 (Melting)
Zircon 1351		k = 12,600
1009		k = 12,600
Sillimanite		k = 2,020 + 5.04 T
K-26		k = 13,500 - 8.32 T
K-20		k = 294 + .529 T
Firebrick		k = 3,620 + .807 T
Unicor 501		k = 12,600
Vegalite		k = 3,050 + 2.85 T
Mineral fiber		k = 716
Glass		$k = 9.35 \times 10^5$

Since the a 2-D model was used, the circumferential water jacket on the GANA charger was divided into top and bottom sections. The water-cooled plunger in this machine was not included because of its transient behavior that can not be studied in the steady state model.

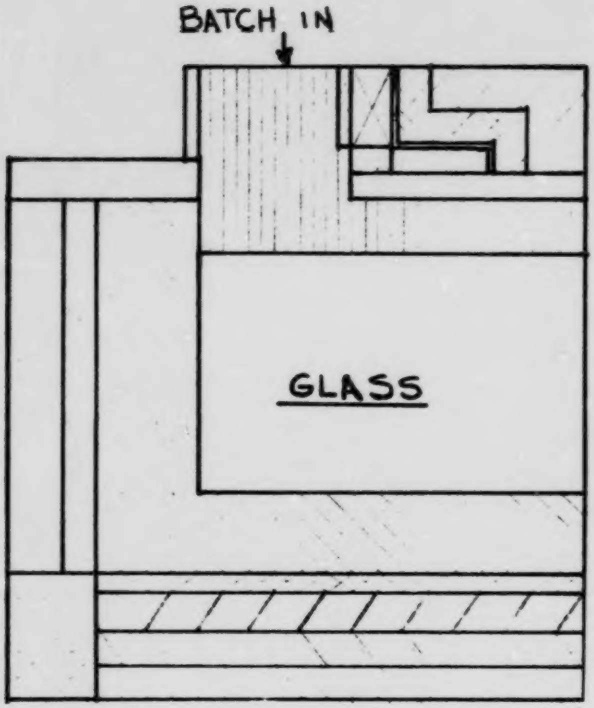
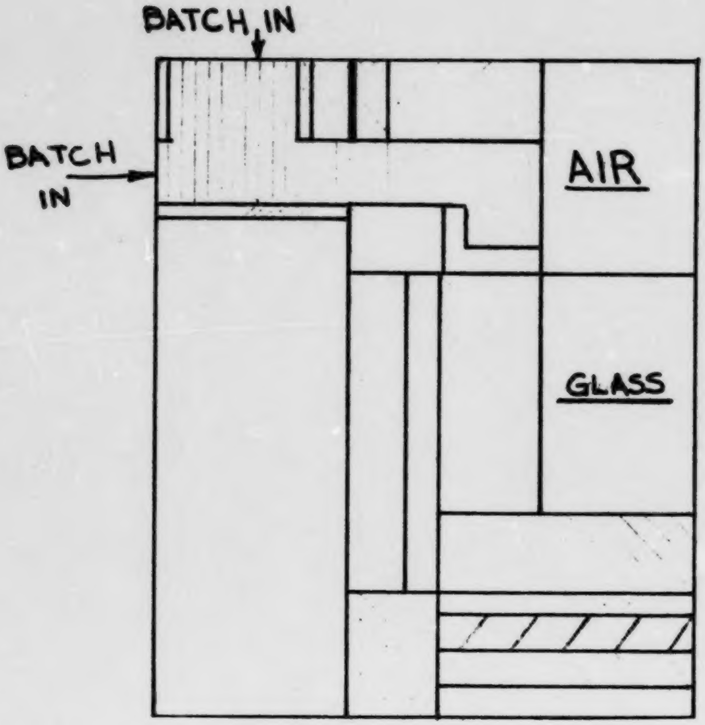

BATCH IN
GLASS

Figure 33. Gana charger 2-D layout.



BATCH IN
BATCH IN
AIR
GLASS

Figure 34. Emhart charger 2-D layout.

Calculations--

Initial computer runs looked at the disparity in thermal losses between the two units for cold pellets, hot pellets, and pellets experiencing melting. The three conditions were simulated by increasing the pellet thermal conductivity with temperature. For the first two cases, there was no discernable difference in thermal losses between the GANA and EMHART chargers, thereby demonstrating the insulating qualities of the batch. However, when the pellets were allowed to melt, the EMHART lost almost twice as much heat as the GANA. Because the water-cooled plunger and the side water panels were not included in the GANA set-up, we would expect higher thermal losses than calculated for the GANA charger. Also, a high thermal conductivity was used in the EMHART unit in the region near the bottom water jacket which caused an inordinate amount of heat short circuiting. Taking these two factors into account, both chargers would be expected to have similar thermal losses. Subsequent computer runs used the EMHART design exclusively.

Lowering the inlet pellet temperature from 800°C to 600°C produced little change in the heat losses but demonstrated the dramatic effect of the bottom water jacket on pellet temperature. Decreases of 540°C were seen near the water jacket surface. The model also showed that if the cooling water was turned off, the pellets would start melting and sticking before they were fully introduced into the furnace entrance.

Because the water jackets removed too much heat from the pellets, a series of computer runs were made wherein the top water jacket was eliminated and the flow rate in the bottom water jacket was varied by changing the heat transfer coefficient in the jacket. Even at very low water flow rates, the ΔT_{pellet} was 430°C. If air cooling was used, it was reduced to 315°C. These large temperature drops occurred because the area of the cooling jacket was so large that a large amount of heat was lost no matter what type of cooling fluid was used.

In an effort to reduce the ΔT_{pellet}, one-inch thick slab of insulation was considered between the bottom water jacket surface and the pellets. At a low water flow rate, ΔT_{pellet} rose to 200°C; however, with air cooling it was only 40°C.

Conclusions--

1. The heat losses in the GANA and EMHART units were similar.
2. The EMHART cooling jackets take out a large amount of heat from the pellets, cooling them to such and extent that preheating advantages are lost.
3. With insulation on the bottom cooling jacket, only air cooling will produce an acceptable ΔT_{pellet}.

Recommendations--

1. Decrease the size of the bottom cooling jacket.
2. If the physical dimensions of the bottom cooling jacket are not changed, then insulation of variable thickness is needed. This thickness will change depending on the cooling fluid used.

Cold Modeling

Test Equipment--

This study was conducted in a 46 cm in Hartford charger with a simulated (wood) furnace backwall. A 7.6 cm high x 38 cm wide pusher blade was used. Figure 35 shows a sketch of this equipment.

Experiments--

The independent variables were pusher blade stroke, speed, backwall opening, and trough slope (to simulate the batch pile inside the furnace). A feed rate of 227-318 kg/hr for loose batch and 318-635 kg/hr for pellets was desired.

After initial testing, it was apparent that a minimum stroke of 4.6 cm and a minimum speed of 10 strokes/min were sufficient for the desired feed rate range and thus they were maintained for future tests.

Calculation and Results--

The bulk densities of wet batch (8% water), dry batch, and batch pellets used in the cold flow modeling trials were measured. They were 1357, 1509, and 1177 kg/m^3, respectively. Based on these bulk densities, the theoretical resistant-free feed rate could be calculated for the minimum stroke and speed used throughout the testing.

The pusher bar displacement was:

$$7.6 \text{ cm} \times 38 \text{ cm} \times 3.02 \text{ cm} = .876 \times 10^{-3} \text{ m}^3$$

Thus, at 10 strokes/min (600 strokes/hr) the hourly volume displacement was .525 m^3. Theoretical feed rates were calculated to be:

Pellets	-	.525 x 1177 = 618 kg/hr
8% Wet Batch	-	.525 x 1357 = 712 kg/hr
Dry Batch	-	.525 x 1509 = 792 kg/hr

However, the feed rates actually encountered with the charger set at its widest opening (19 cm) and with the steepest slope on the trough (short of encountering free flow of pellets) were:

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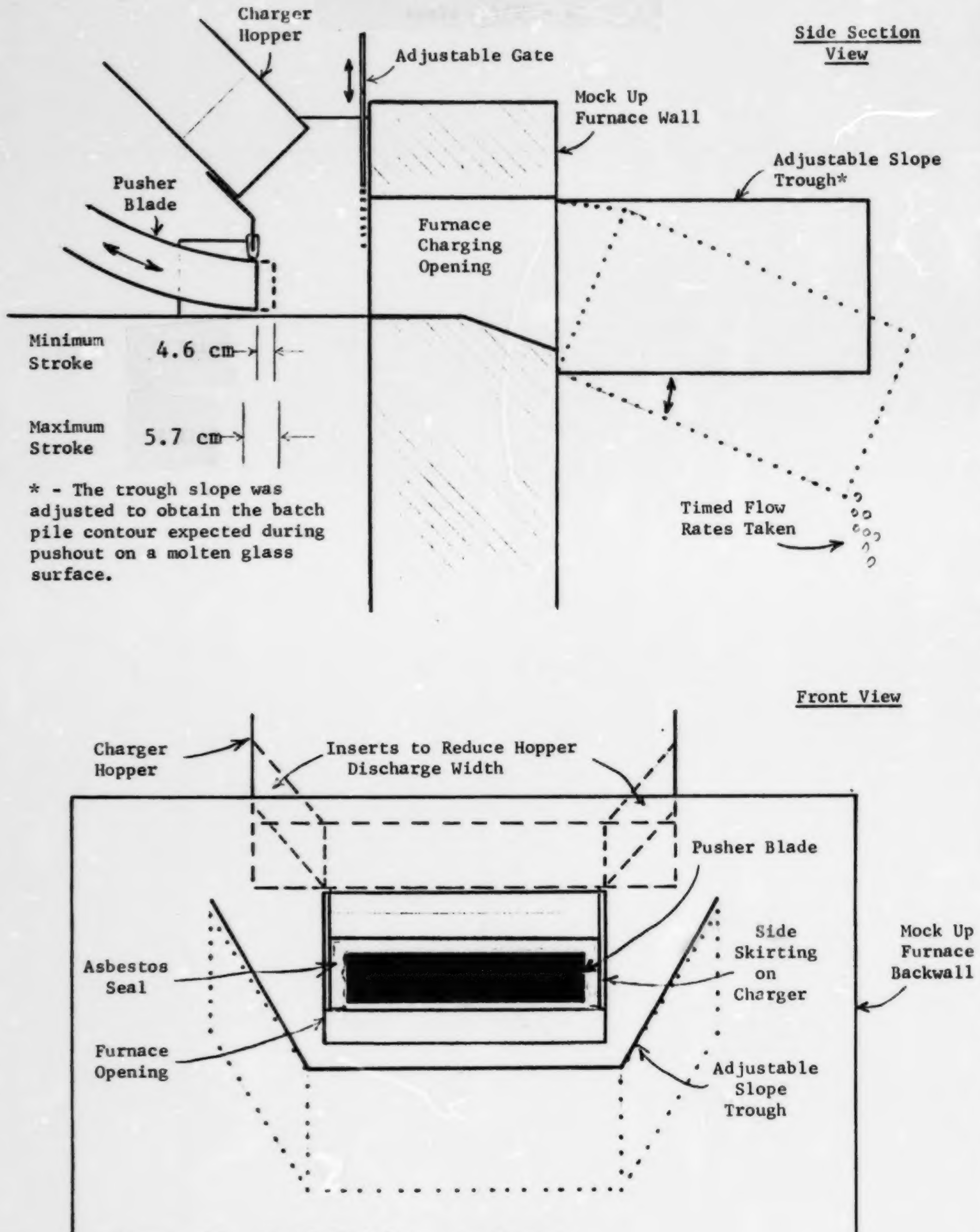
Side Section View
Charger Hopper
Adjustable Gate
Mock Up Furnace Wall
Adjustable Slope Trough*
Pusher Blade
Furnace Charging Opening
Minimum Stroke
4.6 cm
Maximum Stroke
5.7 cm
Timed Flow Rates Taken
Front View
Charger Hopper
Inserts to Reduce Hopper Discharge Width
Pusher Blade
Side Skirting on Charger
Mock Up Furnace Backwall
Asbestos Seal
Furnace Opening
Adjustable Slope Trough

* - The trough slope was adjusted to obtain the batch pile contour expected during pushout on a molten glass surface.

Figure 35. Cold modeling equipment.

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a decrease in pusher bar width from 38.1 cm to 15.2 cm would be necessary to allow more continuous feed and operation within the control range of speed and stroke, for throughputs in the range of 227 - 635 kg/hr.

Calculations and Recommendations--
To obtain nearly constant feed in the 227 to 635 kg/hr. range, a 45.7 cm charger must be reduced in size. It was also found that the theoretical displacement (flow rate) of the different batches very closely compared to the actual flow rates measured under least resistant flow conditions.

No blockage problems were encountered with any of the batch forms with the exception of wet loose batch (without cullet). This batch showed a tendency to bridge at the hopper discharge opening. Vibration eliminated this problem. Although bridging was not encountered with loose wet batch and 20% cullet mixture, provisions should be included for charger hopper vibration to protect against this possibility.

The fine loose batch material showed a tendency to ball up during wetting. The wetting for the cold flow studies was done in a common cement mixer. Due to this balling up tendency, redesign of conventional batch wetters will be necessary to achieve effective wetting with fine materials.

MELTING STUDIES

Glass Properties

The MS-11 batch was chosen as the recommended starting batch for melting studies since this batch exhibited the best pelletizing, drying, and preheating properties. Measurements were made of the melts from the batch composition of the chemical composition, the physical properties, and the electrical resistivity. Overall the studies evaluated the quality of the glass melts.

Glass samples were analyzed for oxide composition. The oxide compositions of the batch and glass are given below.

TABLE 23. Oxide Compositions

	Percent by Weight	
Oxide	Batch	Glass
Na_2O	13.0	12.8
K_2O	0.40	0.38
Al_2O_3	2.00	2.03
MgO	1.74	1.59
CaO	9.36	9.56

The physical properties of a melt of MS-11 glass batch and the average values of physical properties for container glasses produced in the United States are shown in Table 24. The MS-11 glass density and thermal expansion were lower than average while the strain point, annealing point, and softening point were higher than average. The MS-11 properties were found not to deviate significantly from the average values.

TABLE 24. PHYSICAL PROPERTIES

	MS-11	Avg. of container glasses
Density (gm/cc @ 20°C)	2.487	2.5018
Softening point (°C)	737	724
Annealing point (°C)	554	549
Strain point (°C)	510	509
Average coefficient of thermal expansion x 10^{-7}/°C (0-300°C)	84.1	87.5

Viscosity and resistivity measurements were made for a temperature range from 779°C to 1321°C. Graphical representations of this data are presented in Figures 36 and 37.

Comparative Melting of Preheated Pellets and Loose Batch

Description of the Procedure--

The purpose of these laboratory melting studies was to compare the melting behavior of two or more candidate batches under identical melting conditions, as specified by melting temperature and melting time. The melting behavior was measured by counting all seeds (gas bubble inclusions) and grains (unmelted batch particles) remaining in a small sample of glass after it had undergone a specified time and temperature history.

The glass batches to be studied were divided into 50 gram melts. The raw materials used were representative samples of production raw materials, not reagent materials. Melting was done in a platinum crucible approximately 4.5 cm in diameter and 6.4 cm high. The melting furnace was electrically heated by silicon carbide rods, and the furnace chamber temperature was controlled to within ±5°C. After melting for a selected time at a selected temperature the glass was annealed in the crucible. A 2.5 cm diameter core drill was used to remove a sample core from the center of the cooled crucible. A vertical (radial) slice of glass approximately 2.5 cm thick was taken from the core for examination under a 15x microscope and then the total numbers of seeds and grains in the slice of glass were counted separately and converted to seeds/kg and grains/kg. The glass sample counted was approximately 1 cm x 1 cm x 0.25 cm, or 0.25 cm^3.

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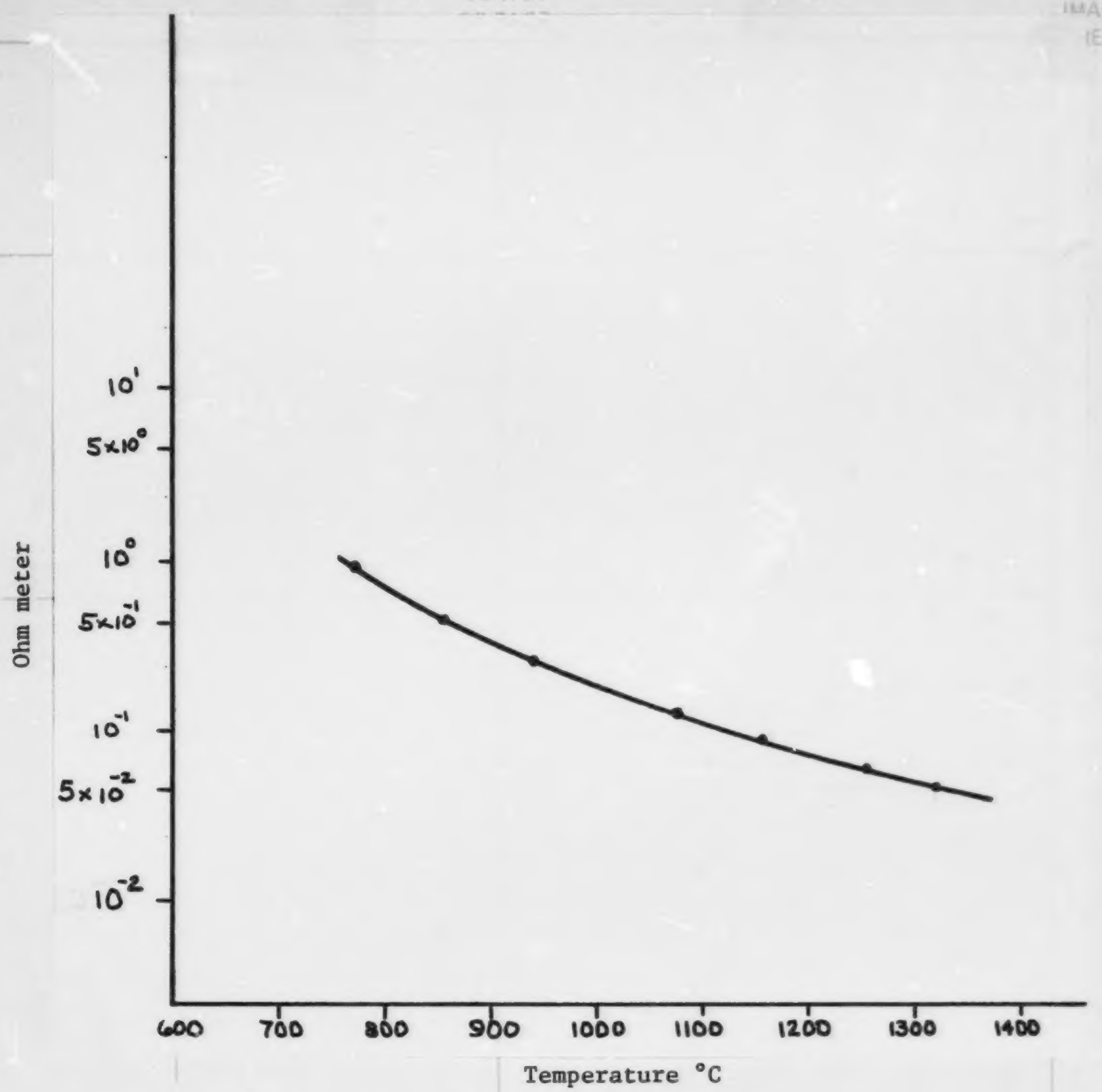

Figure 36. MS-11 resistivity versus temperature.

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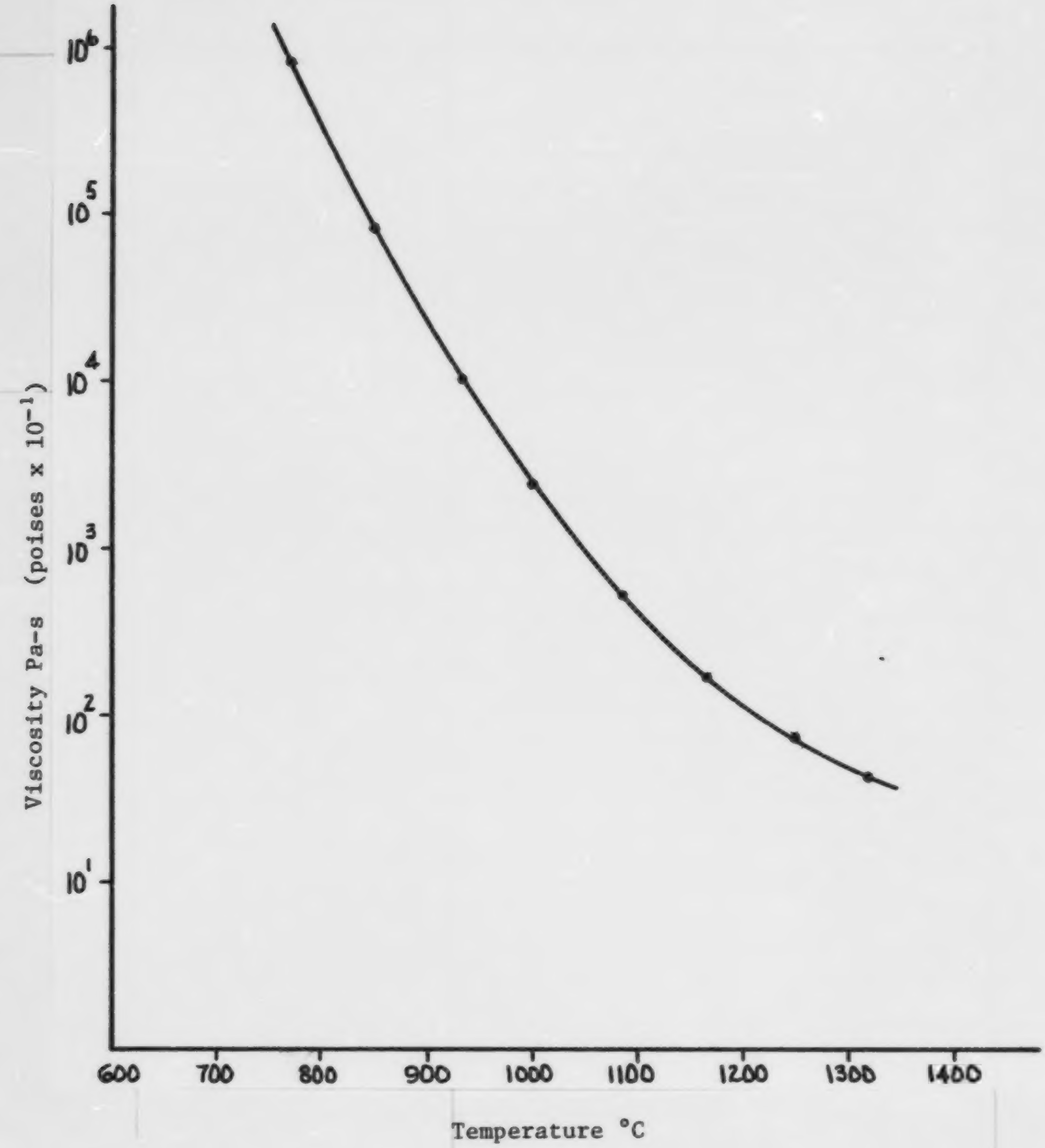

Figure 37. MS-11 viscosity versus temperature.

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Experimental Design--

Seven batches and pellet types were chosen for comparison. All seven batches were prepared to yield glass of identical oxide composition, although different raw materials were used.

Sample #1 was a typical soda-lime container batch with a substitution of burned dolomite for dolomitic limestone. Sample #2 was the same as #1, but was lacking carbocite. Sample #3 used dolomitic limestone. Sample #4 was MS-11 batch containing burned dolomite and 200 mesh sand. Samples #1 through #4 were melted as a loose batch as opposed to an aggomerated batch.

Sample #5 was a group of MS-11 pellets derived from Sample #4. These were dried at 100°C. Sample #6 similarly was a group of MS-11 pellets based on #4 and preheated to 800°C. Sample #7 was a group of MS-11 pellets from #4 which were preheated to 600°C. Sample #5, #6, and #7 were melted as pellets in these experiments. The pellets from Sample #6 were reheated to 800°C for 15 minutes before the melting study began to simulate the feeding of hot pellets to a glass furnace. Similarly, the pellets of Sample #7 were reheated to 600°C for 15 minutes before melting. To check the repeatability of this work each batch was melted twice. The compositions of Samples #1 through #7 are listed in Table 25.

TABLE 25. MELTING BATCH COMPOSITIONS

	Sample			
	#1	#2	#3	#4, 5, 6, 7
Sand	684.1	684.1	683.7	478.9
Sand, 200M Supersil				205.5
Limestone	134.3	134.3	134.3	134.4
Dolomitic limestone	0	0	75.1	0
Burnt dolomite	38.9	38.9	0	38.9
Soda ash	203.9	203.9	203.9	203.9
Nepheline syenite	82.8	83.8	82.8	82.8
Sodium sulfate	6.0	6.0	6.0	6.0
Carbocite	0.62	0	0.62	0.62

The initial group of melts consisted of Samples #1 through #6 melted at 1400°C for 24 minutes. In the next group all seven samples were melted at 1450°C for 45 minutes. Finally Sample #6 was melted at 1400°C for 45 minutes and 1450°C for 24 minutes.

Four different time-temperature conditions were chosen to cover a broad range of operating conditions in soda-lime furnaces. The defect level in these melts was higher than that of typical soda-lime glass products. However, this was necessary in order to have statistically significant seed and grain counts.

The test results are indicated in Table 26. At 1400°C for 24 minutes the six samples show distinct differences in grain concentrations, but only the preheated pellet sample, #6, was significantly different in seed concentration. The fewest grains were found in Samples #4 and #5 which, as loose materials and pellets, contained the largest fraction of fine raw materials. Sample #6 contained the same five materials; however, the 800°C preheat probable destroyed some of the carbocite. Sample #2 lacked carbocite by design and showed high grain concentrations similar to #6. Grains in both #2 and #6 were seen microscopically to be agglomerations of many smaller grains. Samples #1 and #3 had relatively coarse materials and the normal level of carbocite, and show intermediate grain concentrations. Thus, raw material grain size and carbocite concentration may be important in final grain counts in the crucible melts even though residual grains were not indicated as a quality problem for container glass.

At 1450°C for 45 minutes, the preheated pellet Samples #6 and #7 have relatively lower seed concentrations and higher grain concentrations than the other samples. Because seed removal is more critical than grain melting in soda-lime glass manufacturing, the behavior of Samples #6 and #7, the preheated pellets, is considered to be superior to the behavior of the other five. A graphical representation of the highlights of these results is given in Figure 38.

It is interesting to compare the data for Sample #3, the typical loose container batch, to the data for #6, the preheated pellets. For samples melted at 1450°C, preheated pellets melted for 24 minutes had fewer seeds but more grains than loose batch melted for 45 minutes. For samples melted for 45 minutes, preheated pellets melted at 1400°C had fewer seeds but more grains than loose batch melted at 1450°C.

Overall, the results of the crucible studies clearly indicate that preheated pellets melt significantly better than typical unconsolidated batch materials of the same oxide composition.

TABLE 26. TEST RESULTS

		1400°C 24 minutes	
	Sample	Seeds/g	Grains/g
#1	Coarse loose with burned dolomite	790/847*	243/312
#2	Coarse loose without carbocite	820/1020	616/812
#3	Coarse loose with dolomitic limestone	626/839	265/52
#4	Fine loose	712/631	25/27
#5	100°C dry pellets	815/763	64/110
#6	800°C preheated pellets	402/582	878/908
		1450°C 45 Minutes	
#1	Coarse loose with burned dolomite	86/209	3/5
#2	Coarse loose without carbocite	294/189	5/7
#3	Coarse loose with burned dolomite	162/133	2/5
#4	Fine loose	100/108	2/7
#5	100°C dry pellets	258/191	0/2
#6	800°C preheated pellets	15/10	10/7
#7	600°C preheated pellets	32/10	12/17
		1450°C 24 Minutes	
#6	800°C preheated pellets	78/69	59/39
		1400°C 45 Minutes	
#6	800°C preheated pellets	115/69	152/120

* 1st melt/2nd melt

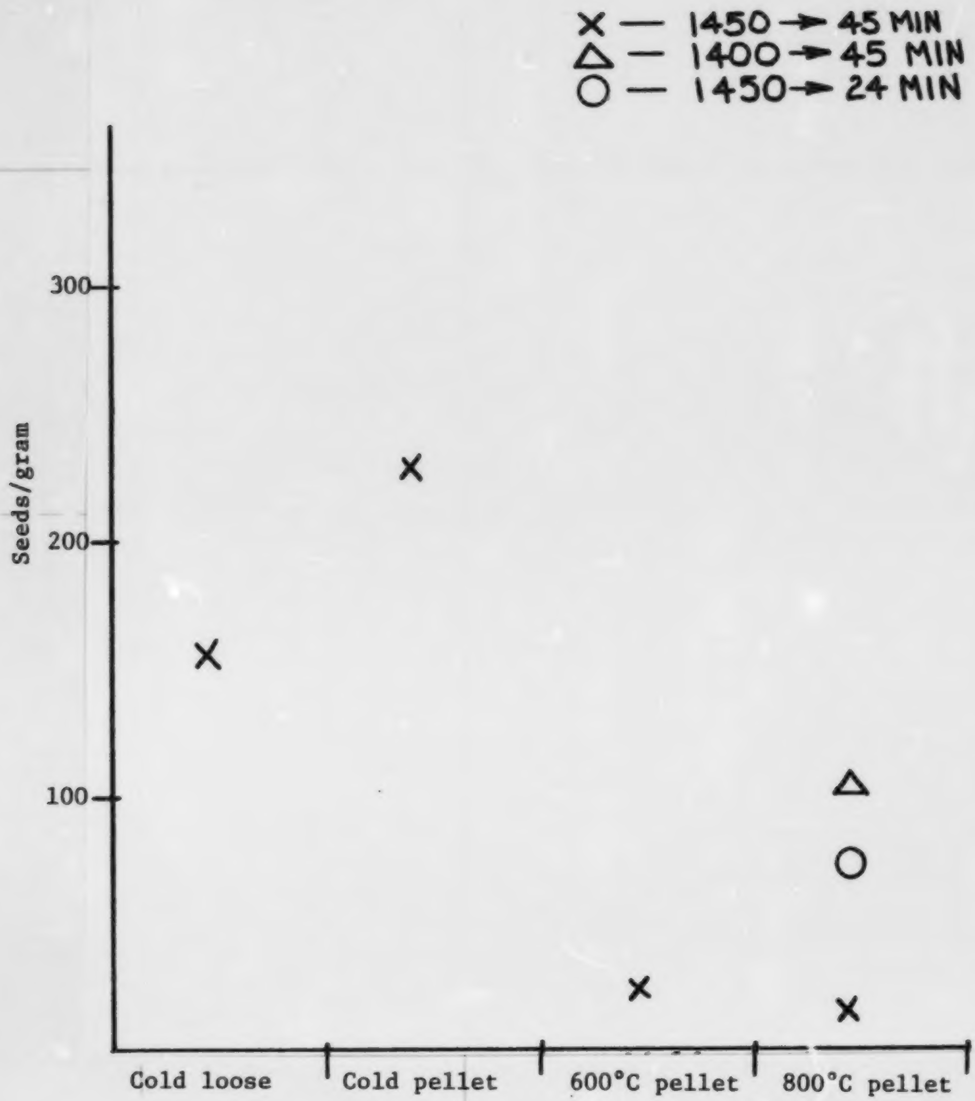

Figure 38. Crucible melting studies.

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SECTION 5

ECONOMIC POTENTIAL

INTRODUCTION

The glass industry is a significant user of energy. Estimates indicate that in 1972, it ranked ninth in energy consumption, consuming approximately 388 x 10^{15} Joules (368 x 10^{12} Btu) of energy. This is 25% of the energy consumed by the U.S. manufacturing sector.

The economic viability of the preheating concept is tied directly to its potential for reducing energy consumption in the glass melting process and will probable determine its acceptance by the glass industry rather than any pollution reduction benefits. Therefore, to predict the potential impact of the utilization of this concept in a full-scale production situation, preliminary economic studies were conducted based on results determined and reported in this document. To carry out these studies a number of manufacturing scenarios were developed and compared to existing manufacturing processes. The following discussions present the scenarios evaluated and the conclusions derived from those evaluations.

Basic Scenarios

The glass industry typically uses regenerative and recuperative systems to preheat combustion air in fossil fuel fired furnaces. Regenerators consist of chambers filled with checker refractory bricks, and are located on the sides of cross-fired melters or on the ends of end-fired melters. Exhaust waste gases from the furnace are passed through the chambers to heat the refractory. Air drawn through the opposite side cools the refractory but, in turn, is preheated prior to entering the furnace for combustion of the fuel. Approximately every 20 minutes the cycle is reversed along with the reversal of fuel to the appropriate burners.

Recuperators are heat exchangers wherein hot waste gases and combustion air travel in separate channels adjacent to one another. Heat is transferred from the waste gas to the combustion air. Gas and air flows are continuous since there is no reversing cycle with this mode of heat exchange. The energy potential benefits of preheating are discussed below for both regenerative and recuperative systems.

Regenerative Furnaces--

In order to quantify energy savings and provide a base for the economic analysis, two base cases are used. The first is a 136×10^3 kg/day soda-lime glass, side port, gas fired, regenerative furnace with an electrostatic precipitator on the stack. The second is a furnace of similar design also fitted with electrostatic precipitator, with double the melting area, capable of producing 272×10^3 kg/day of the soda-lime glass. These cases bracket typical container glass furnaces, which reportedly operate around 181×10^3 kg/day.

The Phase I crucible melting results indicate that comparable glass quality (seed counts) was achieved in half the melting time when using pelletized batch preheated to 800°C, as compared to using normal unheated loose batch. Likewise, the melting temperature was reduced 50°C with preheated batch (same melting time) without increasing seed counts. Phase I work, described earlier, indicates up to 66% reduction in Na_2SO_4, 75-85% reduction in SO_x, and up to 65% reduction in NO_x emissions. Therefore the following three scenarios have been assumed which take advantage of the faster melting capability of pelletized-preheated batch and eliminates the need for a pollution abatement device. Table 27 summarizes the scenarios and base case furnaces. Note that Scenarios A and C are 136×10^3 kg/day furnaces and are compared with a Base 1 furnace (also 136×10^3 kg/day) to obtain the savings. Scenario B is a 272×10^3 kg/day furnace and is compared with a Base 2 furnace (272×10^3 kg/day) for the savings.

TABLE 27. SCENARIO AND BASE CASE COMPARISON SUMMARY

Scenario	Output 10^3 kg/day	Batch type	Furnace melt area (m^2)	Furnace temp (°C)	Pollution device
A	136	Preheated	60.4	1440	No
C	136	Preheated	30.2	1490	No
Base 1	136	Regular	60.4	1490	Yes
B	272	Preheated	60.4	1490	No
Base 2	272	Regular	120.8	1490	Yes

Scenario A represents the case of an existing furnace with no need for increased output. By lowering the furnace temperature 50°C, there is some energy savings and the furnace life is significantly lengthened. Because refractories are an energy intensive product, this indirectly represents additional energy savings (not considered here).

Scenario C represents the situation where a new 136 x 10^3 kg/day furnace is needed and the choice is between a 60.4 m^2 furnace with conventional batch or a 30.2 m^2 furnace using pelletized-preheated batch.

Scenario B typifies an expanding market situation where the output of an existing furnace could be doubled with preheated batch rather than enlarging the furnace. A modification of this scenario (Scenario D) could be the consolidating of the output of two furnaces into one, and shutting down the other.

Furnaces with Recuperators--

The use of metallic recuperators has not been generally accepted in the container glass industry because a higher air preheat temperature is possible with regenerators. However, when the total furnace heat balance is considered, the energy efficiency differences are negligible because of the following offsetting advantages of furnaces with metallic recuperators:

- Less heat is lost from the melting zone through the ports. Recuperative furnaces are "steady state" with no "ingoing" ports. Only one or two "outgoing" ports are required to handle the products of combustion. The fuel is reversed periodically on the regenerative furnace and in the case of the Base 1 furnace, there are 4 ports on each side of the melt zone for a total of 8.
- The surface area of the recuperator is small compared with that of the pair of regenerators, resulting in a lower structure heat loss.
- With "sealed in" burners and steady state operation (no firing reversals), it is possible to consistantly run closer to stoichiometric conditions (less excess air). This is also helpful for NO_x emissions.

The fiber glass industry has essentially adopted the recuperative furnace because the steady state operation gives more consistent control of glass properties. Where comparisons have been possible, they have found very little difference in energy efficiency between the two furnace systems.

It is situations wherein 800°C waste gases can be used for other purposes, such as batch preheating, that the recuperative furnace has a distinct advantage over the regenerative systems. It is for this reason that energy savings will also be shown for the same three scenarios in which the regenerators have been replaced by a recuperator.

Furnace Energy Requirements

For the two base cases involving regular loose batch and the three production scenarios using pelletized preheated batch, there are three furnace sizes, two melting temperatures and two production rates. In addition, energy predictions have been made for all three scenarios in which it is optional to use a recuperator.

To make the energy predictions, the Base 1 condition was extrapolated from an existing Corning furnace for which a complete heat balance had been made. Modifications were assumed to be based on soda-lime glass melting practice. The energy requirements for all the other conditions were calculated with the aid of an existing heat balance model and a mini computer. More details are covered in Appendix D and E.

Principle guides used to make the energy predictions:

The furnace structure losses vary with the ratio of melting areas to the 0.7 power. When the furnace melt area is doubled, the structure losses increase by a factor of $2^{0.7}$ or 1.62. Furnace aging and insulation factors are assumed to be the same for all conditions and therefore were neglected in this study.

A long standing rule of thumb is that furnace structure heat losses vary with the square of temperature ratio. Therefore, by reducing the typical furnace bridge wall temperature 50° from 1490°C, the heat loss should be reduced by a factor of 0.934 $[(1440/1490)^2 = 0.934]$.

The melting energy for the typical soda-lime glass is composed of:

a) The energy required to promote the chemical reactions, which for a similar glass is 465×10^3 joules/kg.

b) The energy required to heat the cullet and glass making materials to the furnace distributor temperature.

The latter energy value can be calculated from the glass specific heat which in turn can be estimated from the glass oxide composition (based on a technique developed by Sharp and Ginther)(7). Table D-4 in Appendix D shows the specific heat values and BTU/lb for a typical soda-lime glass using the Sharp and Ginther technique. For the three scenarios with preheated batch, it was assumed that the pellets reached 800°C in the preheater with 25% of the chemical reactions taking place before the batch entered the furnace. Some batch heat loss in the filling machine is anticipated, so the energy calculations have been made assuming the batch enters the furnace at 600°C. As an example, the glass melting energy for the Base 1 furnace is as follows: (Using Table D-4)

4,536 kg/hr (glass from batch) x 465 x 10^3 joules/kg = 2.1×10^9 joules/hr

12,500 kg/hr (total glass) x 1656 x 10^3 joules/kg = 9.4×10^9 joules/hr

Total energy = 11.5×10^9 joules/hr

The assumption was made that no fuel would be required in the preheater because ample energy is available in the waste stack gases. The critical question, however, is the temperature of the waste gases. Furnaces with metallic recuperators will have waste gas temperatures in the range of 800°C and above, while those of regenerative furnaces will be considerably lower. The two key reasons are (a) that the regenerators can transfer more heat from the waste gas to the combustion air, and (b) the regenerator and flue system are not air tight, as indicated by stack measurements with over 200% excess air. Up to now, there has been no strong incentive to reduce the infiltration of cold air or to better insulate the regenerators because the typical glass manufacturing process does not utilize the stack waste heat. From a pollution abatement equipment point of view (electrostatic precipitators), the emphasis has been to do just the opposite and reduce the waste gas temperature.

For Scenarios A, B, and C the furnace regenerator and flues have been presumed to be sealed (as per current CORNING practice) to reduce the air infiltration and improve the regenerator insulation, thereby reducing the structure heat loss about 30%. The computer heat balance program has indicated that, in addition, the combustion air preheat temperature would have to be reduced 100°C (from 1000°C) in order for the flue gas temperature to reach 800°C. This, in actual practice, would mean removing some checker brick which would increase the fuel consumption slightly. The energy predictions for Scenarios A, B, and C took into account the above factors which are believed necessary to achieve an 800°C waste gas temperature.

In replacing the regenerators with a recuperator, the key energy related differences are:

- The combustion air preheat temperature drops from 1000° C to 600° C.
- The total port area is reduced by 65% (the number of ports drops from 8 to a maximum of 2).
- The structure heat loss from the recuperators is 60% lower than from the pair of regenerators.

Based on the available data, the fuel consumption of the base case furnace should be essentially the same, whether regenerators or a metallic recuperator are used.

Technically, the best systems approach for a furnace with batch preheating appears to be to use a recuperator. The naturally higher waste gas temperature is consistant with the batch preheater requirement from both a temperature and layout point of view. However, this does not mean that regenerative furnaces are excluded; it means more attention has to be given to regenerator/flue design and maintenance.

On another furnace of similar size to the Base 1 case furnace (melting 90.7 x 10^3 kg/day of another glass type) the stack abatement exhaust fan has a 93.2 KW motor and uses about 75 KWH/hr of electric power. The electrostatic precipitator requires about 25 KWH/hr for a total of 100 KWH/hr. The power requirements for the exhaust fan to the preheater has been estimated at 50 brake HP (40 KWH/hr) with about 20 KWH/hr for the pelletizers, which total 60 KWH/hr.

The conveying and filling equipment for the pelletized-preheated batch is not anticipated to be significantly different from that being used with conventional batch; therefore, the energy requirements for these motors is expected to be a trade-off.

Therefore, from the information available to date, it appears that the fan and pelletizer energy requirements for batch preheating will be less than the fan and precipitator requirements for the pollution abatement equipment. However, for these energy saving calculations and economic analysis, an energy trade-off has been assumed.

Energy Savings

Table 28 summarizes the gross energy requirements for the two base case regenerative furnaces and the energy savings for Scenarios A, B, and C with regenerative furnaces. The data assumes that the regenerators and flues have been sealed and better insulated, and that the combustion air preheat temperatures have been reduced in order to get a flue gas temperature of 800°C.

The Base 1 furnace (136 x 10^3 kg/day) had an energy consumption of 7.6 x 10^6 joules/kg and the Base 2 furnace (272 x 10^3 kg/day) consumed 6.8 x 10^6 joules/kg. The energy savings were the lowest for Scenario A and highest for Scenario B. By using the weighting factors (See Table 29), which presumes that half the industry furnaces would utilize the advantages of batch preheating by reducing furnace temperature (Scenario A) and the other half by doubling the melting rate (Scenarios B and C), an average energy savings of 1.52 x 10^6 joules/kg is indicated.

TABLE 28. SUMMARY OF ENERGY SAVINGS

Base Conditions with Regular Batch and Pollution Device, Scenarios A, B, and C are Regenerative Furnaces with Pelletized--Preheated Batch.

Scen-ario	Output 10^3 kg/day	Furnace melt area (m^2)	Furnace temp (°C)	Furnace energy		Energy savings 10^6 joules/kg
				10^9 joules/hr	10^6 joules/kg	
A	136	60.4	1440	36.8	6.48	1.12
C	136	30.2	1490	32.2	5.68	1.93
Base 1	136	60.4	1490	43.0	7.61	---
B	272	60.4	1490	54.9	4.84	1.95
Base 2	272	120.8	1490	77.0	6.79	---

TABLE 29. WEIGHTED AVERAGE ENERGY SAVINGS

I. Regenerative furnaces

Scenario	Energy savings (10^6 joules/kg)	Weighting factor	Product
A	1.12	0.50	0.56
C	1.93	0.25	0.48
B	1.95	0.25	0.49

Average savings for regenerative furnaces = 1.53 x 10^6 joules/kg

II. Recuperator furnaces

Scenario	Energy savings (10^6 joules/kg)	Weighting factor	Product
A'	1.64	0.5	0.82
C'	2.10	0.25	0.53
B'	2.08	0.25	0.52

Average savings for recuperative furnaces = 1.87 x 10^6 joules/kg

III. Weighted average savings

1.60 x 10^6 joules/kg

Table 30 is similiar except that the furnace in all three scenarios have metallic recuperators. Using the same weighting factors (Table 29) the weighed average energy savings is 1.86 x 10^6 joules/kg. Again presuming 75% of the furnaces will continue using regenerators and 25% change to recuperators, an industry weighted average energy savings of 1.6 x 10^6 joules/kg results.

Battelle Columbus Laboratories (8) estimate that the container industry will produce 14.9 x 10^9 kg of good product in 1980. At a selection rate of 90%, this indicates a furnace output of 15.7 x 10^9 kg/yr. At 1.6 x 10^6 joules/kg savings, this is a potential energy savings of 25.1 x 10^{15} joules/year. If 35% of the glass container industry furnaces utilize the batch preheating technology, an annual savings of 8.4 x 10^{15} joules would be possible. This is equivalent to 1.4 million barrels of oil per year, or 227 million cubic meters of gas per year.

The above estimates of energy savings are probably conservative. For example, if by adding batch preheating to the base case 136 x 10^3 kg furnace it becomes a 272 x 10^3 kg furnace and a similar capacity furnace can be shut down. The energy savings are estimated to be 2.78 x 10^6 joules/kg for the regenerator case and 2.9 x 10^6 joules/kg with a recuperator. These are energy savings in the 36% to 38% range and are more than a million joules/kg higher than the assumed average of 1.6 x 10^6 joules/kg used to estimate the industry wide energy reductions.

POLLUTION ABATEMENT

Nature of the Problem

The glass industry is not a significant emitter of air pollutants when compared to many other heavy industries, but pollutants are emitted. These can be divided into two broad categories; particulates and gases. The nature and amount of these emissions vary considerably within the glass industry, depending upon the type of glass and the production method used. In recent years, glass manufacturers' attention has been directed primarily at methods for capturing particulates. Baghouses, scrubbers, and electrostatic precipitators have all been examined for the collection of particulates; the collected material is difficult to handle and there is usually a significant economic penalty associated with the use of such devices.

Particulate emissions consist primarily of submicron condensates of sodium sulfate that result from a combination of a gas such as sulfur oxide and an alkali such as sodium. These particulates are usually white in color and have a low index of refraction. Under these conditions the opacity of the plume, as measured by Ringlemann number, is high even at a relatively low particulate concentration. Arrandale (6) has recently pointed out that with 0.4 micron white particles, Ringlemann No. 2 is exceeded at a

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TABLE 30. SUMMARY OF ENERGY SAVINGS

Base Conditions with Regular Batch and Pollution Device,
Scenarios A', B' and C' are Recuperative Furnaces with
Pelletized--Preheated Batch.

Scenario	Output 10^3 kg/day	Furnace melt area (m^2)	Furnace temp (°C)	Furnace energy 10^9 joules/hr	Furnace energy 10^6 joules/kg	Energy savings 10^6 joules/kg
A'	136	60.4	1440	33.9	5.97	1.64
C'	136	30.2	1490	31.1	5.5	2.10
Base 1	136	60.4	1490	43.0	7.61	---
B'	272	60.4	1490	53.4	4.71	2.08
Base 2	272	120.8	1490	77.0	6.79	---

concentration of only 0.05 x 10^{-3} kg/m^3 under standard conditions. The normal emissions from a glass container furnace melting a flint glass are frequently many times this value.

The submicron condensates can adhere to refractories and metals in the regenerator and exhaust gas ducting. Buildup of particulates in metal preheaters has been reported (6). The composition and behavior of these condensates varies and depends upon the composition of the glass being produced. For container glass, a sodium sulfate-based condensate usually forms. Collection and handling of these particulates is made difficult because of their low bulk density, described as having the consistency of cobwebs, hygroscopic tendency, and acidic potential.

Many factors are reported to affect the rate of particulate emissions (6,9). Temperature of the molten glass is a significant variable because it controls the volatilization of sodium. For most glasses, a reduction in sodium volatilization from the surface of the molten glass is one of the more effective ways of controlling particulate emissions. However, a glass melting furnace operates most efficiently near its design output, and if temperature were reduced, output would be curtailed. On the other hand, the use of preheated glass batch is expected to permit a lowering of the furnace temperature with no loss in production.

Gaseous emissions from container furnaces consist primarily of sulfur and nitrogen oxides. Sulfur oxides are derived primarily from sulfur materials added with the glass batch and to a lesser degree from sulfur in the fossil fuel used. The sulfur is added in compound form, for example, sodium sulfate to aid in melting and refining (removing entrapped gas bubbles) the molten glass. Over half of the sulfur added is chemically incorporated in the glass. The amount of sulfur oxide emitted will vary, and for a container glass it will usually range from 40 ppm to about 300 ppm (6,10). Specific furnaces may deviate because emissions are especially dependent upon furnace operating conditions. The bulk of the emission is usually in the sulfur dioxide form.

Even though sulfur oxide emissions may not exceed current emission standards for sulfur oxides, their elimination would be desirable. For technical processing reasons, sulfur cannot be eliminated from the glass batch, hence a most effective means for removing it from the waste gases is to chemically scrub it out. As discussed later, this is definitely possible by passing the gases through a bed of pelletized, preheated glass batch.

The nitrogen oxide emission problem is one that the glass industry will face in the future. Stationary combustion sources, such as glass melting furnaces, will probably be required to meet standards more stringent than are normally achieved in a conventional fossil fuel fired melting furnace. A complete understanding of the formation of nitrogen oxides in glass melting furnaces does not exist. They appear to be both thermally and chemically derived. Measurements on container glass furnaces indicate that emissions generally vary from a low of about 100 ppm up to 1400 ppm. Typical emissions are probably between 300 and 800 ppm (6,9,10). A portion of the nitrogen oxide emissions are tied closely to the temperature of the melting furnace. It seems reasonable to believe that control of nitrogen oxides in fossil fuel-fired glass melting furnaces may be controlled by lowering melter temperature, coupled with better control of the combustion process. If preheated glass batch permits a reduction in melting furnace temperature, then nitrogen oxides emissions will be reduced. This is shown by Ryder and McMackin (9) where oxides of nitrogen increased dramatically from 100 ppm to over 600 ppm as the furnace load was increased; the increase being attributed to the higher temperatures required for increased production rates.

Effect of Preheating on Pollution Control

Preheating glass batch can help reduce gas and particulate emissions in two ways. It can permit a reduction at the source--the melting furnace, and secondly, it can be used to scrub emissions from the waste gases and recycle them back to the melting furnace.

A reduction in furnace operating temperature through the use of preheated glass batch is certainly reasonable. The results cited by Giegerich (11), Zelignyak (12), Kistler (13), and Manring (14) would indicate that temperatures could be lowered by 50 to 100°C.

As shown previously, the Phase I crucible melting results indicate that comparable glass quality (seed counts) could be achieved with a 50°C lower temperature when using pelletized batch preheated to 800°C, as compared with using normal unheated loose soda-lime batch. Such a reduction of 50°C in furnace backwall temperature can be expected to result in a 50% reduction in total particulate emissions, as cited by Ryder (14). Whether the production rate is kept constant and the temperature lowered, or the temperature held constant and the production rate increased, is a decision involving many technical and business factors.

Sodium Sulfate (Na_2SO_4) Emissions--

With particulates, data reported (6) in the literature on the buildup of particulates in secondary heat exchangers and regenerators encourages one to believe that a similar phenomenon will occur in the preheater where the gases follow a torturous path. In this case, the particulates would adhere on the glass batch agglomerates and be recycled to the melting furnace.

It is felt that several particle deposition mechanisms can contribute to the removal of particulate material from the waste gas stream and its collection in the packed bed of pelletized batch. Airborne particles passing through a packed bed can deposit on the agglomerate surfaces by Brownian diffusion, by inertial impaction from the changing gas flow directions, by direct interception, and by thermophoresis. Thermophoresis is the movement of particles in a temperature gradient toward cooler temperatures. In the case where the packed bed is being heated by the hot waste gas, the thermophoretic velocities of the airborne particles can lead to their deposition on the surfaces of pelletized batch material. This principle of thermophoresis is found in particulate samplers and is particularly applicable in situations where the size of the airborne particles is small. The theory for filtration in packed beds is reviewed in a recent article (5).

As noted previously, static bed experiments have demonstrated a 32% Na_2SO_4 capture for 10 micron radius particles present in the gas stream (See Figure 39).

In the same section, analyses show that when scaling up from the bench scale preheater to the pilot plant preheater, a trade-off exists between particle pollutant size and bed height. The same 32% capture can be expected for particles in the 0.5 micron range using a 3 meter bed height than for particles in the 20 micron range with a 17.5 centimeter bed height.

Reduction of Na_2SO_4 added to batch--

Analysis of the preheated pellets showed that the pellets captured excessive amounts of sulphur. Therefore, it will not only be possible to remove some of the sodium sulfate added to the mixed batch, but it will probably be necessary. This will contribute to additional pollution benefits.

A basic question to be answered in Phase II is whether or not the Na_2SO_4 particulate captured on the surface of the pellets will contribute to glass fining. If all of the Na_2SO_4 captured on the surface is volatilized in the furnace, we must rely on the Na_2SO_4 input in the cold pellets for fining. If prereaction allows the Na_2SO_4 input to be reduced by one third, then the particulate emission can be reduced by 44% when the maximum SO_3 allowable in the glass is 0.1%. If the SO_3 retained in the glass is allowed to increase to 0.2% as a result of reduced furnace temperature, particulate emissions can be reduced by 77%. These reductions in particulate emissions are for a base case with a Na_2SO_4 input of 0.4% in the batch and are independent of the particulate capture efficiency in the preheater.

On the other hand, if the Na_2SO_4 captured on the pellet surface contributes to fining as much as the Na_2SO_4 input in the cold pellets, the particulate emissions reduction depends on the preheater capture efficiency. Based on bench scale results, we

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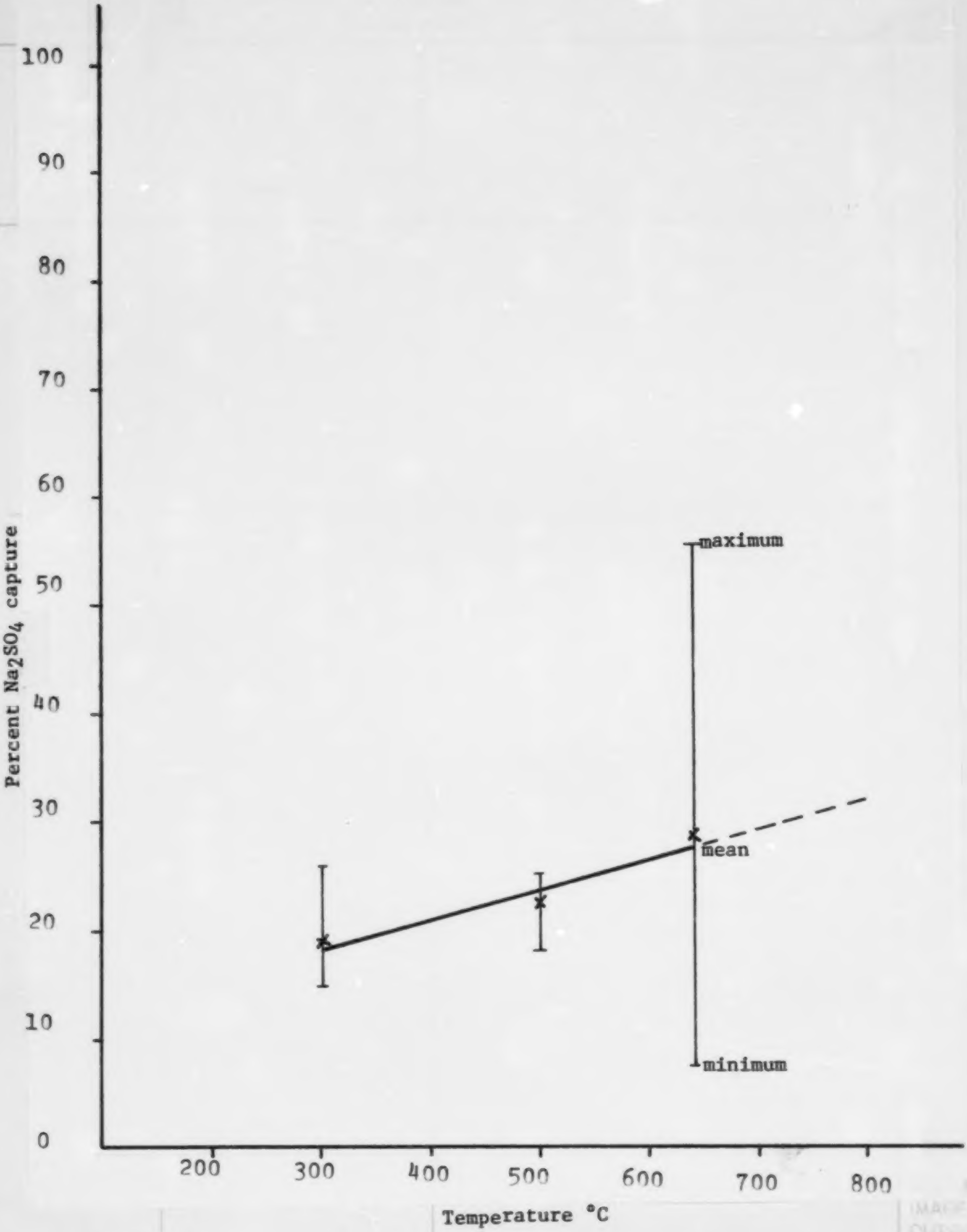

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Figure 39. Na_2SO_4 capture in bench scale preheater.

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can assume that the particulate efficiency of the preheater is 33% and that prereaction enables the total Na_2SO_4 (batch input plus captured particulate) fed to the furnace to be reduced by one third. In this case, particulate emissions can be reduced by 55% or 82% when the allowable SO_3 in the glass is 0.1% or 0.2%, respectively. Again, these reductions are for a base case Na_2SO_4 input of 0.4%.

SO_x Reduction--

Capture and recycle of emissions from the waste gases can also be expected to occur. The feasibility of removing sulfur oxides from combustion products by passing these gases through packed beds of calcium carbonate or sodium bicarbonate has been demonstrated by the utility industry. Similar results can be achieved with preheated, pelletized glass batch. The concept is the subject of at least one patent (17) and an article (17) where such emissions are scrubbed from waste gases passing through the glass batch layer in an electric glass melting furnace.

Bench scale static bed experiments indicate that soda-lime glass batch pellets preheated to 800°C can capture from 75-85 percent of the SO_2 present in a gas flowing at 0.426 m/sec. Figure 40 illustrates these results.

NO_x Reduction--

A reduction in furnace temperature can be expected to bring about a reduction in volatilization from the molten glass surface and a reduction in nitrogen oxide formation. The combined effect of a 50°C reduction in temperature and its associated 15% reduction in fuel can result in a 65% reduction in NO_x emissions (See Figure 41 and Reference 6).

ECONOMIC ANALYSIS

Introduction

This is an updating of the economic analysis made in the initial proposal. It also adds to the work done by Arthur D. Little, Inc. which reviewed several energy conservation options open to the glass industry (17). In short, the information gained since then indicates potentially higher energy savings and probably higher capital costs.

There are still many unknowns concerning the costs of pelletizing and preheating equipment for 136 x 10^3 Kg/day and 272 x 10^3 Kg/day production furnaces. Because of the uncertainties related to pellet strength and the degree of drying needed (if any) between the pelletizer and the conveyor leading to the dryer-preheater, a great deal more process flexibility is being built into Phase II equipment than will be required for the first production system. The production equipment estimates are as realistic as possible at this time.

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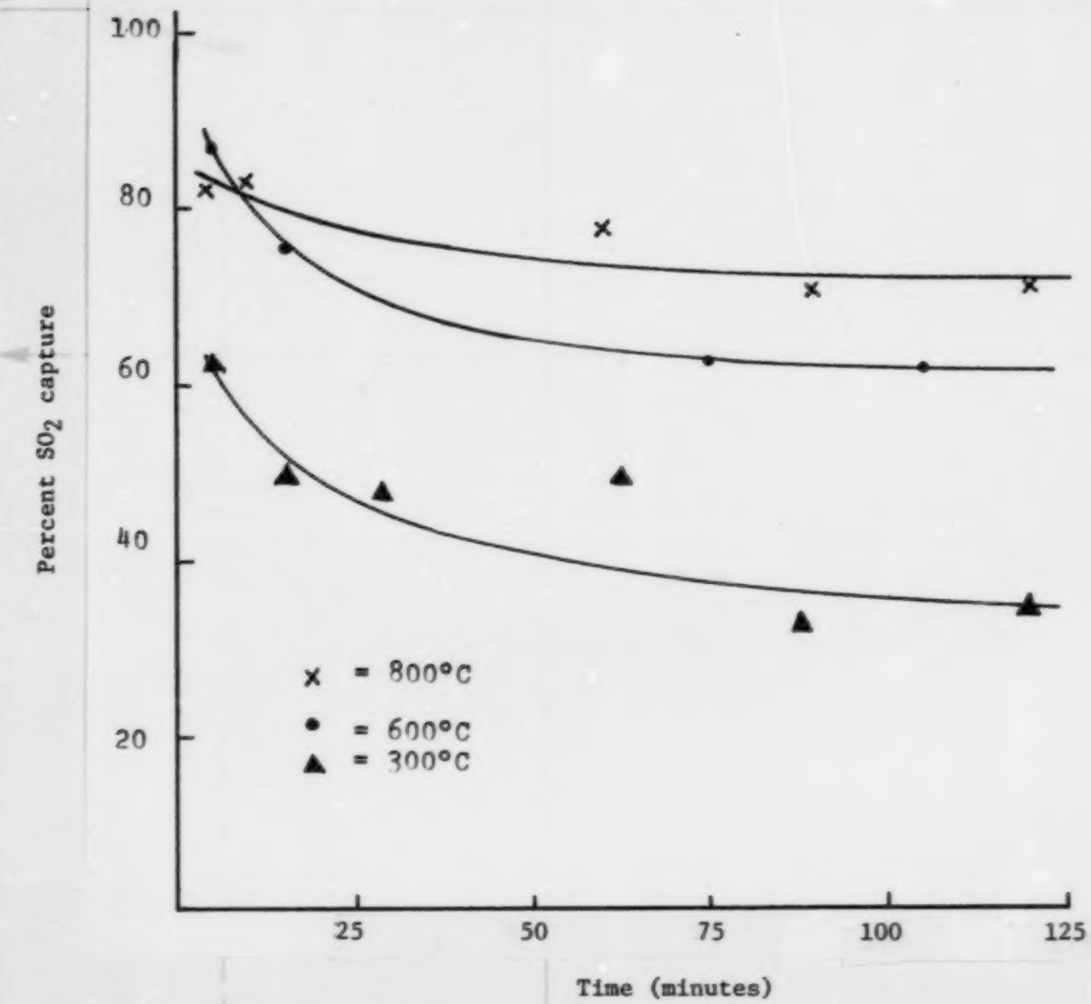

Figure 40. SO_2 capture at different temperatures with a velocity of 0.426 M/sec.

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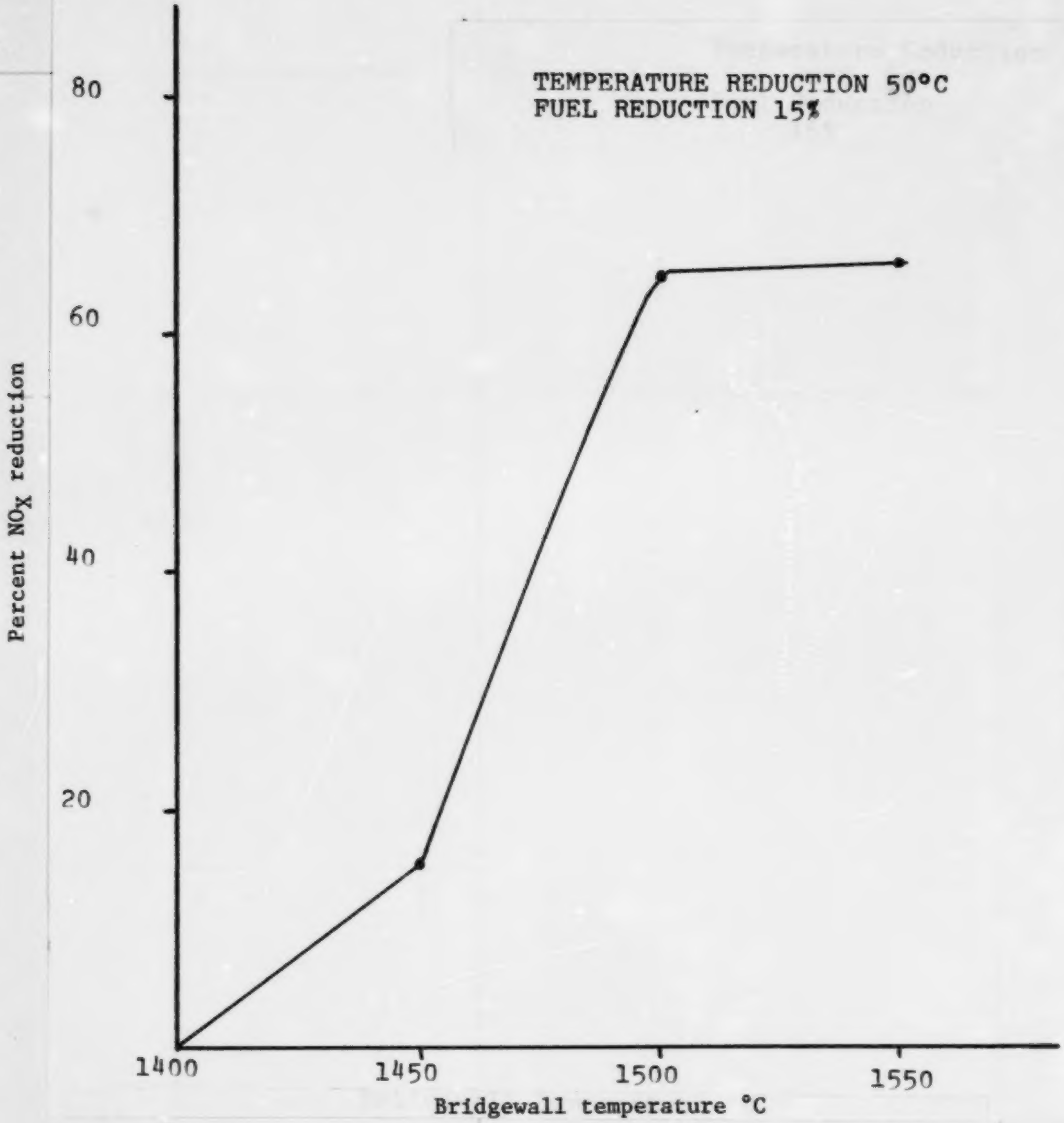

Figure 41. Reduction in NO_X emission as a function of temperature.

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The crucible melting studies indicate that melting rates can be doubled by using pelletized batch preheated to 800°C. The faster melting potential can also be utilized by lowering furnace temperatures 50°C or more. The scenarios used for the economic analysis are the same as those used to develop the energy savings.

To quickly review, the Base 1 condition is a 60.4 m^2 cross-fired regenerative furnace producing 136 x 10^3 Kg/day of soda-lime glass with conventional batch and requiring an electrostatic precipitator to meet air pollution requirements. The Base 2 furnace is similar except that it has double the melt area and double the output. The three scenarios in the analysis are furnaces using pelletized-preheated batch, with their respective energy savings as shown in Table 31.

TABLE 31. ENERGY SAVINGS

Scenario	Compares with	Furnace melt area (m^2)	Furnace temp °C	Output (10^3 Kg/day)	Energy savings (J/kg) with regenerator	Energy savings (J/kg) with recuperator
A	Base 1	60.4	1440	136	1.12	1.64
C	Base 1	30.2	1490	136	1.93	2.11
B	Base 2	60.4	1490	272	1.95	2.08

In scenario A, the Base 1 furnace temperature is reduced 50°C resulting in a significant increase in furnace life and a modest reduction in furnace energy. Although not reflected in the economic analysis, the reduction of stack emissions will probably be greatest for this scenario.

New furnaces are required in scenario C, and the choice is between the Base 1 furnace (60.4 m^2 melt area) with conventional batch and a smaller furnace (30.2 m^2 melt area) using pelletized-preheated batch.

Scenario B compares the cost of adding pelletized-preheated batch to the Base 1 furnace with the doubling of its capacity vs. enlarging the furnace from 60.4 to 120.8 m^2. The enlarged unit is defined as the Base 2 furnace.

It has been presumed that the industry could be applying batch preheating technology by the end of 1980; therefore, the estimates have been made on that basis. Those estimates that have been made in 1978 Dollars, for example, are inflated at the rate of 6 1/2 percent per year. Daily or hourly operating data have been translated to yearly figures on the basis of 8000 operating hours per year.

Melting Costs

In making economic comparisons of glass melting processes, the elements of cost that Corning typically examines are:

- Energy
- Accrual (pro rated repair costs)
- Batch
- Labor
- Pollution abatement

In the economic analysis, only the incremental costs are needed. Therefore, the labor costs included are only those over and above the normal furnace operating requirement. It is the extra manpower required to operate the pelletizer-preheater or the pollution device that is shown. Likewise, the only electric power included is that needed to operate additional equipment. Regular batch must be mixed, transported, elevated, and filled into the furnace; so the additional equipment includes the pelletizer and preheater. The exhaust fan and electrostatic precipitator are also included in this category.

Energy--

The energy requirements for the two base furnaces filled with conventional batch and the three scenarios using preheated batch are the same as those discussed previously and tabulated in Table 27.

Each year CORNING updates a forecast of average corporate energy costs looking 10 years into the future. This forecast suggests that by the end of 1980, the cost of oil will be $\$3.36/10^9$J, and gas will be $\$2.89/10^9$J. Assuming a 50/50 fuel mix by then, the average cost is $\$3.13/10^9$J, which is the energy cost used for this economic analysis.

Using the same 10 year projection, the cost of gas would be $\$6.82/10^9$J in 1987, and for oil would be $\$6.35/10^9$J. If we assume a fuel mix of 3/4 oil and 1/4 gas, the average cost would be $\$6.45/10^9$J. This is more than a doubling of the fuel cost in 7 years (1980-87). The energy savings obviously will be increasing with time.

The energy requirements for the pelletizer-preheater have been estimated as follows:

Exhaust fan - 50 brake HP	40 KWH/hr
2 pelletizers, each with 15 HP motor	20 KWH/hr
Total	60 KWH/hr

The other conveyors and elevators are expected to be similar to existing equipment; therefore, the energy differences can be neglected.

Actual data from an electrostatic precipitator installation on a 60.4 m^2 furnace shows the following:

3 ϕ 125 HP exhaust fan (440 Volts, 100 amps/phase)	75 KWH/hr
Electrostatic precipitator	25 KWH/hr
Total	100 KWH/hr

Although the above data indicates that the operation of the pelletizer-preheater will require less energy than the pollution device, we are taking the conservative approach and considering the two to be a trade-off for this economic analysis.

Accrual--

For this purpose, the accrual cost is the prorated cost of repairing the furnace. Table 32 summarizes the accrual data used for the base furnace and three scenarios.

TABLE 32. FURNACE REPAIR COSTS

	Output	Furnace campaign		Accrual	
Scenario	10^3 kg/day	Rep. cost ($)	Life (yrs)	$/yr	10^{-2} $/kg
Base 1	136	1,000,000	5	200,000	0.44
A	136	1,000,000	10	100,000	0.22
C	136	650,000	5	130,000	0.29
Base 2	272	1,600,000	5	320,000	0.35
B	272	1,000,000	4	250,000	0.28

Incremental Batch Cost--

The laboratory data show that pellet strength improves when the surface area of the batch materials, especially the silica is increased. This is achieved by increasing the proportion of 200 mesh sand in the batch. The amount of pulverized sand, which is more expensive than regular sand, is a key factor in the batch cost, and the answers will not be clearer until we get to Phase II. An incremental batch cost increase of $\$0.22 \times 10^{-2}$/Kg of glass is our best estimate for now.

Incremental Labor--

It has been estimated that one extra man/shift will be needed to run the pelletizer and assist the furnace operator with the batch preheater. Approximately a 1/2 man-day has been needed to clean and handle materials from the electrostatic precipitator.

Scenario A

This scenario assumes that through pelletizing-preheating technology, it is possible to reduce the furnace temperature by at least 50°C and eliminate pollution without a decrease in pull. The scenario is compared with an existing furnace (Base 1) that employs an electrostatic precipitator for pollution control. Table 33 summarizes the operating cost savings as well as the range capital costs for the two approaches.

The energy and accrual savings total \$258,400/year while the incremental batch plus labor costs show a negative savings of \$150,000/year. The net savings is \$108,400/year or $\$0.24 \times 10^{-2}$/Kg. An additional energy savings of \$74,000/year, or $\$0.16 \times 10^{-2}$/Kg, appear possible if the furnace uses a metallic recuperator instead of regenerator. The $\$0.22 \times 10^{-2}$/Kg incremental batch cost stands out as a significant factor in the economic evaluation, and attention will be directed at trying to reduce this cost.

Scenario C

This scenario assumes that a new furnace, 50% of original size, will provide the same pull, the same glass quality, and will abate pollution. This is compared with a new furnace of original size fitted with an anti-pollution device. Table 34 summarizes the operating cost savings and the range capital costs.

In this case, the energy and accrual savings are larger, totaling almost \$345,000/year, or $\$0.76 \times 10^{-2}$/Kg. The incremental batch plus labor costs show a negative savings of \$150,000/year, or $\$0.33 \times 10^{-2}$/Kg. The net result is an annual savings of \$194,560 or $\$0.43 \times 10^{-2}$/Kg. The savings could go up another \$24,000, or $\$0.05 \times 10^{-2}$/Kg with a recuperative furnace.

Scenario B

This scenario assumes that with pelletized-preheated batch the pull rate can be doubled, and the pollution abated. A comparison is made with an expanded existing furnace to be fitted with an anti-pollution device. Table 35 summarizes this scenario.

TABLE 33. ECONOMIC SAVINGS COMPARISON: BASE 1 CASE AND SCENARIO A

	Base 1 case $136\text{x}10^3$ kg/day existing furnace with pollution device	Scenario A $136\text{x}10^3$ kg/day existing furnace with pelletizer/ preheater	Savings $/Yr	Savings 10^{-2} $/kg
Furnace energy:				
Use (10^9 J/ton)		36.8		
Use (10^6 J/kg)	7.60	6.49		
Cost ($/Yr)	1,074,760	921,360	158,400	
Cost (10^{-2} $/kg)	2.4	2.02		0.35
Inc. energy, equipt.	--		0.0	0.0
Accrual:				
Repair cost ($)	1,000,000	1,000,000		
Life (years)	5	10		
Cost ($/year)	200,000	100,000	100,000	
Cost (10^{-2} $/kg)	0.44	0.22		0.22
Incremental batch			(100,000)	(0.22)
Incremental labor	10,000	60,000	(50,000)	(0.11)
Net			108,400	0.24

Additional capital	Base 1	Scenario A	Savings ($)
Furnace	--	--	--
Pollution device	1,600,000		
Pelletizer-preheater		2,300,000	(700,000)
Net			(700,000)

TABLE 34. ECONOMIC SAVINGS COMPARISON: BASE 1 CASE AND SCENARIO C

	Base 1 case 136×10^3 kg/day new 60.4 m^2 furnace and pollution device	Scenario C 136×10^3 kg/day new 30.2 m^2 furnace and pelletizer/ preheater	Savings $/Yr	Savings 10^{-2} $/kg
Furnace energy:				
Use (10^9 J/ton)	43.1	32.2		
Use (10^6 J/kg)	7.60	5.68		
Cost ($/Yr)	1,079,760	805,200	274,560	
Cost (10^{-2} $/kg)	2.4	1.8		0.60
Inc. energy, equipt	--	--	0.0	0.0
Accrual:				
Repair cost ($)	1,000,000	650,000		
Life (years)	5	5		
Cost ($/year)	200,000	130,000	70,000	
Cost (10^{-2} $/kg)	0.44	0.29		0.15
Incremental batch cost			(100,000)	(0.22)
Incremental labor cost	10,000	60,000	(50,000)	(0.11)
Net			194,560	0.42

Additional capital	Base 1	Scenario C	Savings ($)
Furnace	2,000,000	1,250,000	750,000
Pollution device	1,600,000		
Pelletizer-preheater		2,300,000	(700,000)
Net			50,000

TABLE 35. ECONOMIC SAVINGS COMPARISON: BASE 2 CASE AND SCENARIO B

	Base 2 case 272×10^3 kg/day furnace enlarged to 120.8 m^2 with pollution device	Scenario B 272×10^3 kg/day furnace 60.4 m^2 with pelletized/ preheated batch	Savings $/Yr	Savings 10^{-2} $/kg
Furnace energy:				
Use (10^9 J/ton)	77.0	54.9		
Use (10^6 J/kg)	6.79	4.84		
Cost ($/Year)	1,927,200	1,372,800	554,400	
Cost (10^{-2} $/kg)	2.12	1.51		0.61
Inc. energy, equipt	--	--	0.0	0.0
Accrual				
Repair cost ($)	1,600,000	1,000,000		
Life (years)	5	4		
Cost ($/year)	320,000	250,000	70,000	
Cost (10^{-2} $/kg)	0.35	0.28		0.08
Incremental batch			(200,000)	(0.22)
Incremental labor	10,000	60,000	(50,000)	(0.06)
Net			374,400	0.41

Additional capital	Base 2	Scenario B	Savings ($)
Furnace	1,100,000		
Pollution device	2,800,000		
Pelletizer-preheater		4,300,000	(400,000)
Net			(400,000)

TABLE 36. ECONOMIC SAVINGS COMPARISON: TWO BASE 1 FURNACES AND SCENARIO D

	(2) $60.4m^2$ furnaces @ $272x10^3$ kg/day with pollution devices	Scenario D $272x10^3$ kg/day furnace $60.4m^2$ with pelletized/ preheated batch	Savings $/Yr	Savings 10^{-2} $/kg
Furnace energy:				
Consumption (10^9J/ton)	86.3	54.9		
Consumption (10^6J/kg)	7.61	4.84		
Cost ($/year)	2,159,520	1,372,800	786,720	
Cost ($10^{-2}$$/kg)	2.4	1.51		0.87
Inc. energy, equipt	--	--	0.0	0.0
Accrual				
Repair cost ($)	2,000,000	1,000,000		
Life (years)	5	4		
Cost ($/year)	400,000	250,000	150,000	
Cost ($10^{-2}$$/kg)	0.44	0.28		0.17
Incremental batch			(200,000)	(0.22)
Incremental labor	10,000	60,000	(50,000)	(0.06)
Net			686,720	0.76

Additional capital	(2) Base 1	Scenario B	Savings ($)
Furnace			
Pollution device	3,200,000		
Pelletizer/preheater		4,300,000	(1,100,000)

The net savings of Scenario B total \$374,000/year (or $\$0.41 \times 10^{-2}$/Kg) for the regenerative furnace, with an additional \$36,000 saved annually ($\$0.04 \times 10^{-2}$/Kg) if the furnace is recuperative.

A modification of this scenario is shown in Table 36. In this case, the option is between adding pollution devices to two 60.4 m^2 (Base 1) furnaces or batch pelletizing-preheating to one 60.4 m^2 furnace. Both approaches will produce 272×10^3 kg/day of glass. The savings are very significant, almost \$687,000/year ($\$0.76 \times 10^{-2}$/kg). The additional capital required is \$1.1 million, but this does not address the question of forehearth changes that may be required.

A summary of savings and additional capital is included in Table 37.

TABLE 37.

SUMMARY OF SAVINGS AND ADDITIONAL CAPITAL REQUIRED FOR BATCH PELLETIZING/PREHEATING

Regenerative furnace			Additional capital	Recuperative		
Scenario	\$/Yr	10^{-2}\$/kg	\$	10^{-2}\$/kg	\$/Yr	Scenario
A	108,400	0.24	700,000	0.40	182,650	A'
C	194,560	0.43	*	0.48	218,500	C'
B	374,400	0.41	400,000	0.45	410,000	B'
D	686,720	0.76	1,110,000	--	--	--

* \$50,000 less capital required.

TABLE 38. RATE OF RETURN ON INVESTMENT

Scenario[1]	Form of benefits from pelletizing & preheating	IRR	Payback period(yrs)	Base case furnace 10^3 x kg/day
A	Reduce temp 50°C	18.0	5 1/2	136
A'	Reduce temp 50°C	28.0	5	136
B	Increase pull 100%	59.0	3	272
B'	Increase pull 100%	64.0	3	272
D	Shut one furnace off & increase pull on the other 100%	44.0	4	two "136" furnaces
C	Build 50% smaller	∞^2	0	136
C'	Build 50% smaller	∞^2	0	136

[1] Cases A', B', C' are for recuperative furnaces. A, B & C are for a regenerative furnace.

[2] There are both capital and operating savings.

FINANCIAL ANALYSIS

In order to quantify the potential benefits of batch preheating, a financial analysis was made using the savings and incremental capital data derived in the previous section. The data is illustrated in Tables 33, 34, 35, and 36 and summarized in Table 37. The capital cost figures were obtained by making the realistic assumption that an electrostatic precipitator would be needed on the furnace stack, if the batch preheating technology is not used. Table 38 shows that the Internal Rate of Return for the scenarios ranges from a low of 18% to infinity (both capital and operating savings). A reasonable "hurdle rate" from CORNING's viewpoint is 15%, although projects with energy savings may be acceptable with a lower rate of return.

A "Worst Case" assumption was also made which presumed that an electrostatic precipator would not be required for the base case furnaces using conventional batch. In this case, the additional capital requirements would be the total cost of the pelletizing and batch preheating equipment. Internal Rates of Return for these cases are shown in Table 39. It is significant to note that in this table, the rate of return figures are still positive, ranging from 3 to 14%.

TABLE 39. RATE OF RETURN ON INVESTMENT

(Assuming electrostatic precipitators not needed on base case furnaces)

Scenario	Savings ($/yr)	Additional capital ($)	IRR	Payback period
A	108,400	2,300,000	2.9%	15 yr. - 4 mo.
C	194,560	1,550,000	14.0%	7 yr. - 7 mo.
B	374,400	3,200,000	13.5%	6 yr. - 7 mo.

The financial analysis figures are sufficiently impressive to suggest that Phase II experiments should be carried out to obtain harder data.

SUMMARY

Energy

1) Average savings should be 1.52×10^6 joules/kg for regenerative furnaces.

2) Average savings should be 1.86×10^6 joules/kg for recuperative furnaces.

3) A weighted average savings of 1.6×10^6 joules/kg of glass is expected. Assuming that 35% of container furnaces use this technology, an equivalent of 1.4×10^6 barrels of oil/year should be conserved.

Pollution

1) Na_2SO_4 : 44-82% reduction

2) SO_x : 75-85% reduction

3) NO_x : 65% reduction

Economics

1) If a pollution device is needed on the base case furnace:

Operating Savings : $\$0.22 \times 10^{-2}$ - $\$0.77 \times 10^{-2}$/kg
Additional capital : $0 - $1,100,000
IRR : 18 - infinite %

2) If a pollution device is not needed on the base case furnace:

Operating Savings : $\$0.22 \times 10^{-2}$ - $\$0.44 \times 10^{-2}$/kg
Additional capital : $1,550,000 - $3,200,000
IRR : 3 - 14%

SECTION 6

PROPOSED PILOT PLANT DESIGN

The concept being pursued in this proposal is that of making pellets from a soda-lime glass batch, preheating them with waste heat flue gases, and filling the hot pellets directly into the furnace (with the low temperature chemical reactions having been initiated). Results from Phase I bench scale studies discussed in preceeding sections of this report have showed this concept to be a cost effective method of conserving energy and reducing pollution in the glass industry.

The results showed that strong pellets can be made from the batch materials, and they can be preheated at 800°C without sticking together. Furthermore, if filled into a furnace (at 600°C or more) a doubling of the melting rate could be expected.

Before this technology is scaled up to a production facility (150 tons/day or more output) there are many design and operational details that need investigating. Determining more precisely the increase in furnace output over a range of batch preheat temperatures becomes very vital in estimating specific plant energy savings and calculating future economic analyses. The temperature of the furnace waste gases is highly variable within the glass industry, therefore there is no single economic answer. There are design and operational moves that a plant can make to increase the waste gas temperature, and as a result, data is needed which will enable decisions to be made on an individual furnace basis.

While some of the pelletizing technology data could be obtained independent of a melting study, there is no way of defining required pellet properties short of putting them through a typical handling, drying, and filling process. It is known that pellet strength will increase by using more burnt dolomite and 200 mesh sand in the batch, but these materials add to the batch cost. Thus, the batch which produces adequate strength pellets for the lowest cost, must be determined.

Using packed beds for preheating glass making raw materials and immediately filling the hot batch into the furnace is new technology. Packed-bed, counter-flow, heat exchangers have been used in other industries, so a basis exists for their engineering designs. However, empirical data is needed to verify assumptions, provide the necessary data base, and develop the scale-up rules required for future production installations.

It would be desirable for the wet pellets to go directly from the pelletizer to the shaft preheater, with the drying operation integrally combined with the preheating operation. However, since wet pellet strength may be a problem, the pilot plant equipment has been designed to provide the flexibility needed to study the problems of drying independently of preheating. This would provide the necessary data for a combined "systems" design to be used in production.

Pellet integrity, strength, abrasion resistance, homogeneity, size control, and dusting characteristics are some of the properties that will be quantified and evaluated.

The temperature distribution of the pellet bed in the shaft preheater will also be an area of study. Sticking characteristics of the pellets in the region of 800°C need confirming under the load and dynamic conditions of a moving bed preheater.

A pusher type batch charger has been selected because of its universal use by the container and flat glass industry. Modifications have been made because of the higher temperature environment and to reduce batch temperature losses while filling. Actual operating experience is needed to verify the performance of the batch charger.

One of the very important purposes of the pilot plant demonstration is to determine the degree of melting rate improvement with a continuous furnace. It is also important to determine the melting rate increase if the preheater can only be operated at 600°C, or even 400°C. With this broad data base, energy savings for a large number of scenarios can be calculated.

Energy savings are the result of preheating the batch materials (about halfway to furnace temperature) and starting the chemical reactions with waste heat, in combination with distributing the furnace "no-load energy" over more pounds of product (or reducing "no-load energy" with lower furnace temperatures). By determining the percent reduction in J/kg of glass melted with the pilot plant furnace, it will be possible to predict the energy savings for any other furnace.

It was also shown that significant pollution capture is possible in the moving bed preheater. Laboratory bench scale testing showed that 90% of the simulated SO_2 and 32% of the simulated sodium sulfate particulates were captured in a static packed bed. Even though the time-temperature history of the waste gases from the pilot plant furnace may not exactly duplicate those from a regenerative furnace, reliable capture results will be obtained along with a better understanding of the capture capability of a packed bed of pellets.

In preparation for future scale-up to a nominal 150 ton/day melting system demonstration, it is important that certain questions be answered at the pilot plant level of operation. The information derived from these experiments will be of further use in future commercialization of the process.

PROCESS DESCRIPTION

The pilot plant system involves purchasing and installing pelletizing, belt drying, shaft drying, screening, jet pump, packed bed preheater, furnace batch charger, furnace modification, combustion, batch handling, and control systems equipment. Operations consist of operating the system over a period of four months to confirm laboratory results, obtain operating data, establish operating procedures, and obtain scale-up information for commercialization.

There are several contingencies included in the system to answer the many design and operating questions needed for commercialization. For this reason, the pilot plant will contain a pelletizing and drying system, and a preheating and melting system. The two systems will be operated independent of each other, with pelletizing and drying being performed 8-12 hours each day to supply a continuous operation of the preheater and melting system. These two systems are discussed in more detail below.

Pelletizing - Drying System

The present plan is to use an existing batch plant at our Process Research Center for weighing and mixing raw materials as well as cullet crushing and magnetic separation.

The mixed batch will be transported by fork truck from storage to the tote bin discharge station located in the cave (Figure 42). On receipt of a low level signal, the operator starts the elevating system to refill the 910 kg pelletizer surge hopper. Following completion of the elevating cycle and receipt of a low level signal from the weigh-loss-differential feeder, the surge hopper will discharge.

Then, the operator will manually adjust the pelletizer water flow control valve to the required setting. He will also set the feed rate for the weigh-loss-differential feeder. If the water control flow rate to the pelletizer varies, the material flow rate will vary proportionally.

The pelletizer will have variable pan angle, rotational speed, and pan depth. The pellets will contain about 12% moisture which must be removed before introducing the pellets to the furnace. The method and equipment type that will be used for drying in a full scale production unit have not been decided yet, though it seems that the trend will be to use a shaft dryer only.

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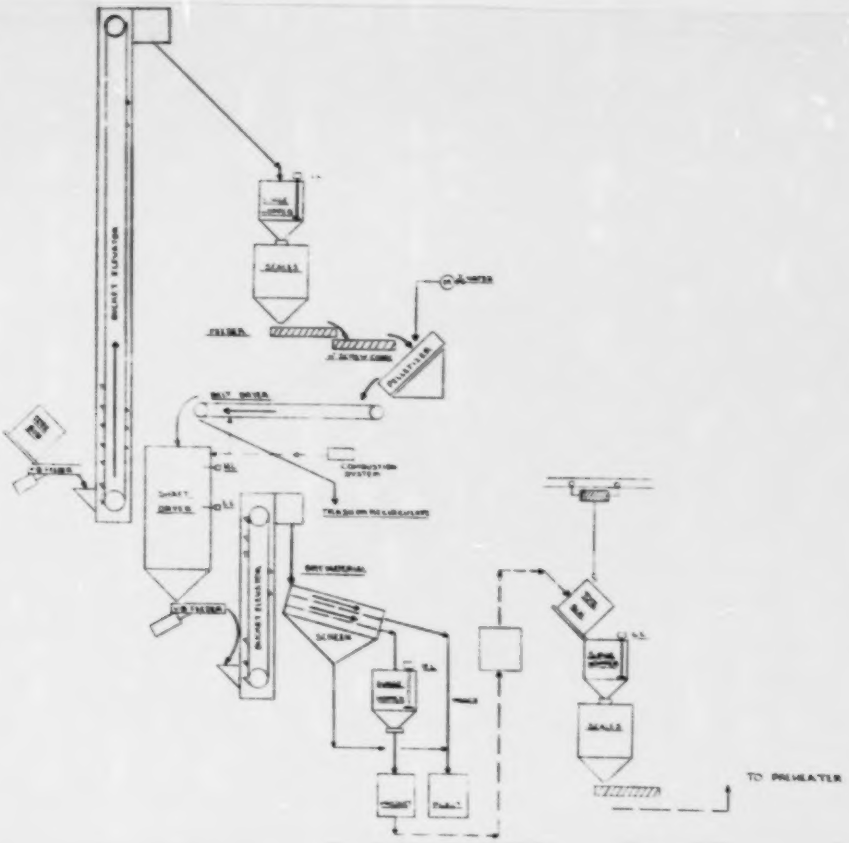
BUCKET ELEVATOR
SCALES
FEEDER
PELLETIZER
BELT DRYER
COMBUSTION SYSTEM
SHAFT DRYER
FEEDER
BUCKET ELEVATOR
DRY MATERIAL
SCREEN
SCALES
TO PREHEATER

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Figure 42. Pelletizing and drying system.

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The drying system (see Figure 42) includes two dryers in series. A belt conveyor dryer which will be fed with wet pellets containing about 12% moisture from the pelletizer at a rate of 950 kg/hr (2100 lb/hr) (dry basis). Up to 25% of the water content will be removed in this dryer to give the pellets enough strength to allow downstream handling. The pellets from the belt will be fed directly into a second shaft dryer where the remainder of the water will be removed. The lower portion of the shaft dryer will have a cooling zone so that the pellets can be discharged into a storage bin at a temperature that does not exceed 100°C.

The belt dryer will be operated by a variable speed motor and will have a spreading device at the feed side to ensure even spreading of the pellets necessary for uniform drying. The belt dryer will be divided into three compartments to control the drying rate of pellets.

The hot gases needed for drying will be supplied from an excess air burner and will be mixed with additional cold air to obtain the desired temperature and flow rate. The temperature control will be automatic and will be based on the amount of natural gas fed to the burner. The flow rate of drying gas going to the belt dryer will be controlled manually by adjusting the amount of cold air mixed downstream of the burner.

The nominal drying gas temperature supplied to the belt dryer will be 350°C and the flow rate will be adjusted to obtain the best results. The gases leaving the first compartment are mixed with the gases leaving the second compartment and then the major part of this mixture is recirculated by a recirculation fan to the second compartment. About one half of the gases leaving the second compartment are sucked through the third compartment for preliminary drying of fresh pellets and discharged through a discharge fan. The assembly of the belt conveyor is shown Appendix C, Figure C-6.

The shaft dryer, (see Figure C-7, Appendix C), has two sections. The upper part will be the drying section and the lower part will be the cooling section. The wet pellets are fed from the top. Hot gas at 350°C, enters the dryer 2.1 meters (7 ft) below the bed level, so that the drying bed will be kept at normal operation. Cooling air at ambient temperature will enter the shaft about 1 meter (3 ft) below the hot gas feed level. This cooling air will cool the pellets to a 100°C, then it will mix with the hot gas to produce an average temperature of 172°C (340°F) at the bottom of the drying section. Thus, in no case will the pellet temperature go above 172°C.

The shaft dryer will operate under positive pressure, estimated to be a maximum of 5 x 10^3 pascals. The hot gas will be supplied by an excess air burner of the same configuration as was described for the belt dryer. A pressure blower of 29.8 KW, 10.3 x 10^3

pascals gage will supply the cold air requirements for the entire dryer system. The pellets feeding section from the belt dryer to the shaft dryer will be located under a hood, with an exhaust fan to avoid dust contamination of the environment. A reject gate is included in this transfer line to take care of any over supply of pellets.

The control system for the shaft dryer will be mostly manual (as was described for the belt dryer). The only exception is that two level sensors, high and low, will be placed near the top of the pellet bed and will control the feed rate of pellets from the bottom of the shaft dryer to the storage bins.

All the controls of the drying system as well as the fans, motors and other auxiliary equipment will be mounted on a single panel.

The rate of material withdrawal from the shaft will be controlled by a two speed vibratory feeder. The vibratory feeder discharges into the elevator that in turns discharges into a screener for fines control. When the product bin at the screen discharge signals full, the operator discharges pellets into a tote bin. This bin is then transferred by fork truck to the dried pellet inventory.

Preheating - Melting System

Tote bins of pellets are transferred from storage by fork truck and freight elevator to the furnace. They are then attached to an overhead hoist and elevated to a discharge stand. The operator opens a discharge gate and the weigh-loss-differential feeder locks into a volumetric feed condition. (Figure 43). On receipt of a low level signal, the flow gate opens and pellets flow into a weigh-loss-differential feeder. Following completion of the discharge cycle, the feeder returns to gravimetric control. Dry pellets are then elevated to the sealing chamber (charge hopper).

The rate of pellet discharge to the preheater is controlled by a two speed feeder slaved to a level indicator located in the preheater sealing chamber. When a low level condition occurs, the feeder will switch to a high rate of feed, and when a high level signal is achieved, the feeder will drop back to a low rate.

The design of the shaft preheater can be seen in Figure C-9, Appendix C. The process diagram is described in Figure C-8, Appendix C.

The level of pellets in the shaft is constant, and the pellet flow rate is controlled through a wiper bar at the bottom exit of the preheater. The wiper bar feed rate is controlled by

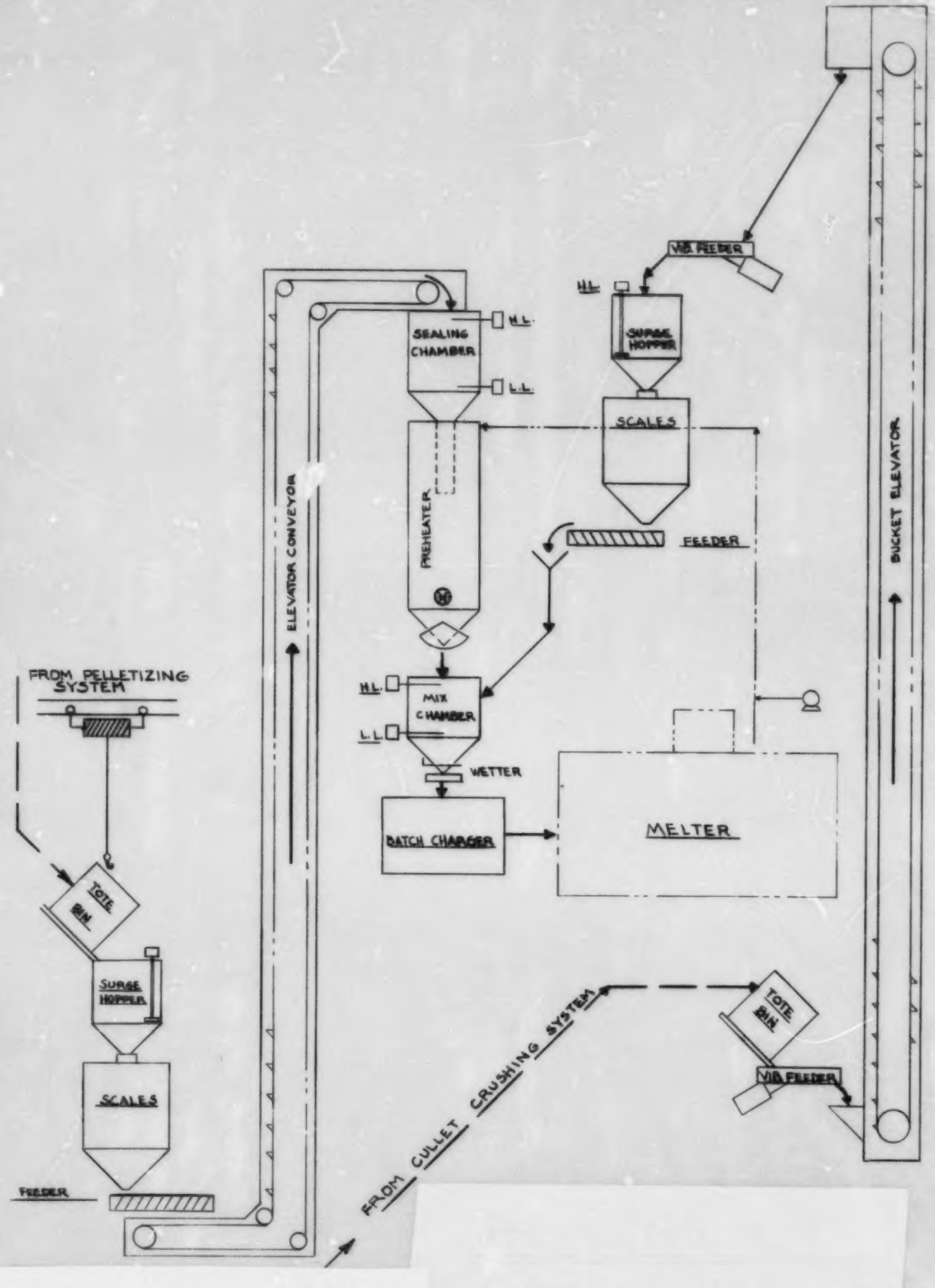
VIB. FEEDER
H.L.
SURGE HOPPER
SEALING CHAMBER
H.L.
L.L.
SCALES
PREHEATER
M
FEEDER
ELEVATOR CONVEYOR
BUCKET ELEVATOR
FROM PELLETIZING SYSTEM
H.L.
MIX CHAMBER
L.L.
WETTER
BATCH CHARGER
MELTER
TOTE BIN
SURGE HOPPER
SCALES
FEEDER
FROM CULLET CRUSHING SYSTEM
TOTE BIN
VIB. FEEDER

Figure 43. Pre-heating and melting system.

the feed rate to the melting tank, and the level in the mixing hopper below the preheater. The pellet level in the charge hopper is controlled by means of changing the feed rate of the conveyor.

Cullet in tote bins is transferred from storage by fork truck to a container discharge stand, elevated, and transferred to a 910 kg storage bin located above the weigh-loss-differential feeder. Upon receipt of a low level signal the feeder will lock into volumetric feed condition and the surge bin will discharge into the feed hopper. Upon completion of the discharge cycle, the feeder will return to gravimetric control.

The cullet will then be elevated and its feed rate will be controlled in the same fashion as the pellet feed rate. In the mixing hopper the pellets mix with cullet to produce a 25% cullet mixture, and feed through a batch charger to the furnace. The pellets will leave the preheater at a temperature between 400°C and 800°C (according to the specific test) and at a flow rate of up to 500 kg/hr (1100 lb/hr).

The preheater will have a 0.25 in carbon steel shell and will be lined with 96.5 cm I.D. (38 in) silica bricks.

The hot gas (max. temp. of 850°C) will be fed to a plenum located approximately 3 meters (10 ft) below the end of the charge hopper feed pipe. Thus, the heating section will be about 3 meters (10 ft) high. The chunk-breaker is placed in the lower part of the preheater to prevent any large chunks from getting to the wiper bar and plugging the discharge.

The wiper bar will be placed in the mixing chamber, and will be hydraulically operated and linked to the chunk-breaker. A hydraulically operated gate will also be placed at the bottom of the mixing hopper to enable the preheater to be separated from the hot pellet feeder for maintenance. The total length of the assembly from the top of the charge hopper to the bottom of the mixing hopper will be 8.93 m (29 ft - 3 1/2 in).

In order to study the effect of gas temperature on the absorption of pollutants by the pellets, four cooling air pipes will be introduced at the top of the preheater to discharge cold air to a plenum 0.8 meters (30 in) below the top of the bed. This cold air will reduce the gas temperature at this level to the desired temperature. The hot gases will be discharged through a 14 in pipe above the bed level.

The furnace flue gas will serve as the energy source for the preheating process. The flue gas has a temperature of 1450°C to 1500°C, which is too high for the preheater requirements.

A jet pump (inspirator) will be used to mix part of the flue gas with cold air and to discharge a stream of gas at the desired flow rate and temperature for the process. This jet pump will use cold air as a primary fluid and the hot flue gas as the secondary fluid. This makes the control valves less expensive because they will be operating at low temperature.

The first control loop will be assigned to control the temperature at the exit of the jet pump. A thermocouple will sense this temperature and will send a signal to the valve controlling the primary jet flow rate (and pressure). By adjusting this pressure, the ratio of primary fluid to secondary fluid in the jet pump will change to give the desired temperature.

The second control loop will control the gas flow rate to the preheater. A mass flow meter will measure the flow rate to the preheater and compare it to a signal coming from a weighing apparatus for the pellets. The set point for the control valve will be determined on the basis of a one-hour average pellet feed rate. The set point in this loop will vary with changes in average furnace pellet pull or flow rate. Minor adjustments of gas flow rate will be made by a third control loop (pressure control loop).

The third control loop will also maintain constant pressure at the exit of the jet pump by activating a control valve which will discharge part of the gas to the atmosphere.

A cold air supply is connected to the exit pipe from the preheater through a manually operated valve. This line will cool the exit gas to a temperature below 300°C, since the fan and control valve downstream are designed to a 315°C maximum. In addition to this system, a protection loop is added at this point that will flood the line with cold air if a high temperature is sensed by the temperature element. A similar protection loop will be used to protect from high temperatures at the exit of the jet pump.

The cold air for the preheater system will be supplied by a high pressure fan (pressure of 13.8×10^3 pascals gage). The preheater will be under negative pressure and controlled by an induced draft fan (40.3 KW and 13.8×10^3 pascals gage), designed for a maximum temperature of 315°C.

The cullet-pellet mixture will be fed into the furnace using a modified batch charger (with the proper thermal insulation) and the melting will be done in a 52 m^2, electrically boosted, direct-fired furnace.

The glass level in the furnace will be controlled by varying the charger speed and furnace pressure will be controlled by an automatic damper above the furnace exhaust vent.

SCHEDULE

The following schedule is planned for Phase II commencing with funding and approval by the Environmental Protection Agency.

Task	Cumulative months for completion
Detail designs and construction drawings	3
Equipment procurement	6
Construction	9
Operation	13
Reporting	18

TEST PLAN

The main plan for the pilot plant experiments is to compare melting rates, energy consumptions, and reductions in pollutant levels for:

1. Fine, wet loose batch
2. Cold dried pellets
3. Hot preheated/prereacted pellets

In addition, there are specific plans for each of the following operations:

Pelletizing

1. Determine minimum batch cost consistent with strength requirements.

2. Measure segregation.

3. Determine stability of operation.
    a. Effect of water flow rate and temperature
    b. Determine the need for gravimetric feed rate control
    c. Determine pellet size distribution

4. Define material losses and time delays during start-up and shutdown of the pelletizer.

5. Measure fines and reduce the fines to an acceptable level.

6. Determine actual manpower and operating requirements.

Drying

1. Determine minimum moisture removal required for handling in order to reduce costs for a production facility.

2. Measure pellet drying rate for different operating parameters.

3. Measure maximum drying temperature to avoid decrepitation of pellets.

4. Determine dryer thermal efficiency.

5. Measure fines and reduce the fines to an acceptable level.

Preheating and Pollution Capture

1. Measure preheating rates for different operating parameters.

2. Determine preheater thermal efficiency.

3. Measure Na_2SO_4, NO_x, and SO_x capture for various operating parameters.

4. Measure Na_2SO_4 capture for a range of particle sizes.

5. Determine degree of prereaction as a function of time and temperature history.

6. Measure refractory lining abrasion.

7. Measure metal parts abrasion and contamination.

8. Determine stability of operation as a function of
   a. Gas flow rate and temperature control.
   b. Fill control.

9. Determine maximum operating temperature without sticking or pellet deformation.

Hot Transfer

1. Determine stability of operation as a function of
   a. Furnace fill control.
   b. Cullet addition control.

2. Determine structure heat loss for different pellet temperatures.

Furnace

1. Measure melting rates for different pellet temperatures.

2. Measure glass quality for different pulls, furnace temperatures, and batch feed conditions. In specific, determine:
    a. Seed and stone counts
    b. Salt cake and carbocite requirements

3. Determine fuel requirements.
    a. Natural gas
    b. Electric boosting, if any

4. Measure Na_2SO_4, NO_x, and SO_x emission levels.

5. Measure dilution rate of furnace gases going to the preheater.

6. Determine the incremental benefits for preheating temperatures of 400°C, 600°C, and 800°C.

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APPENDIX A

INFORMATION ANALYSIS

This task consisted of a review and analysis of available information pertinent to the glass batch pretreatment program. Because related work had been done by others and the details of some of these studies were available, it was important to compile and review this information in order to use it as a basis for the experimentation conducted on the existing program. The available information was primarily in the areas of pelletization, drying, and preheating.

REVIEW OF COLUMBIA GAS INFORMATION

This section reviews pertinent highlights of experimental work conducted in the early 1970's by Columbia Gas System Service Corporation, which did extensive work on the pelletizing and preheating of soda-lime glass batch. Columbia Gas made information available for use in this program. All pertinent information from the Columbia Gas studies was reviewed and considered when selecting raw materials and experimental test conditions.

The majority of the information came from three Columbia Gas reports. These were:

1) "Evaluation of the Effects of Batch Pelletization and Batch Preheating on Glass Manufacture", Final Report By Battelle Columbus Laboratories to Columbia Gas, June 5, 1972.

2) "Drying and Preheating Pelletized Glass Batch", Columbia Gas Report, July 20, 1972.

3) "Pelletizing Glass Batch", Columbia Gas Report, May, 1974.

The Columbia Gas reports covered work done on raw materials selection and grinding, pelletizing, drying, preheating, and melting. The reports themselves contain extensive data which is not duplicated here, but was available during the program. Given below is a synopsis of pertinent information from the Columbia Gas reports.

Materials Selection

All work done by Columbia Gas was with soda-lime glass compositions representative of container glass. These data showed that the particle size of the raw materials is extremely important in the pelletizing, drying, and preheating of glass batch. Studies were performed in which glass batch was ground to various sizes in batch and continuous-grinding equipment. Studies were also conducted on the mixing of previously ground raw materials. It was found that either method could be used to prepare the glass batch as long as the proper particle-size distribution was obtained. The Columbia Gas studies indicated that it was desirable to have approximately 50 percent of the glass batch finer than 74 micron, with at least 30 percent of the silica (sand) being part of this fraction. This constitutes about a six-fold increase in the surface area of the silica over glass sand normally used to make glass containers.

The finer sizes of raw materials were believed needed to produce pellets that have adequate preheat strength during hot transfer to the melting furnace and in which prereaction of batch components is maximized. Pellets were found to lose strength rapidly above 538°C, without the finer silica. It was also found that the finer materials promoted eutectic liquid formation and solid-state reactions within the temperature range of 538°-816°C. Without fine silica, reactions did not occur to a sufficient degree and strength of pellets dropped to zero above 650°C.

Figure A-1 illustrates how the dry strength of various soda-lime glass batches was found to vary as the particle size of the glass batch changed. This indicates the importance of characterizing each glass batch separately rather than lumping all of them together. The nature of these variations was not fully understood. Figure A-2 illustrates how the strength of pellets dropped off when preheated. The pellets containing raw materials having a coarse (but normal) particle size lost their strength above 600°C, while the strength of the pellets containing finer materials leveled off. A burned dolomitic lime was used as the binder in these experiments.

Weight loss from dry pellets that were preheated and soaked for four hours was used as a measure of the reactions occurring. Some weight loss occurred from loss of chemically combined water, but the majority of the decrease was from CO_2 lost when sodium carbonate reacts with other batch constituents. Studies of weight loss demonstrated that for each batch, a linear relationship existed between the loss and temperature. Results also indicated that glass batches containing silica, with a surface area six times greater than normal, had over 80 percent of the sodium carbonate reacted at 760°C. This indicated the formation of metasilicate compounds, which are desirable from a melting point of view, that is, they will contribute to lowering the temperature in the melter.

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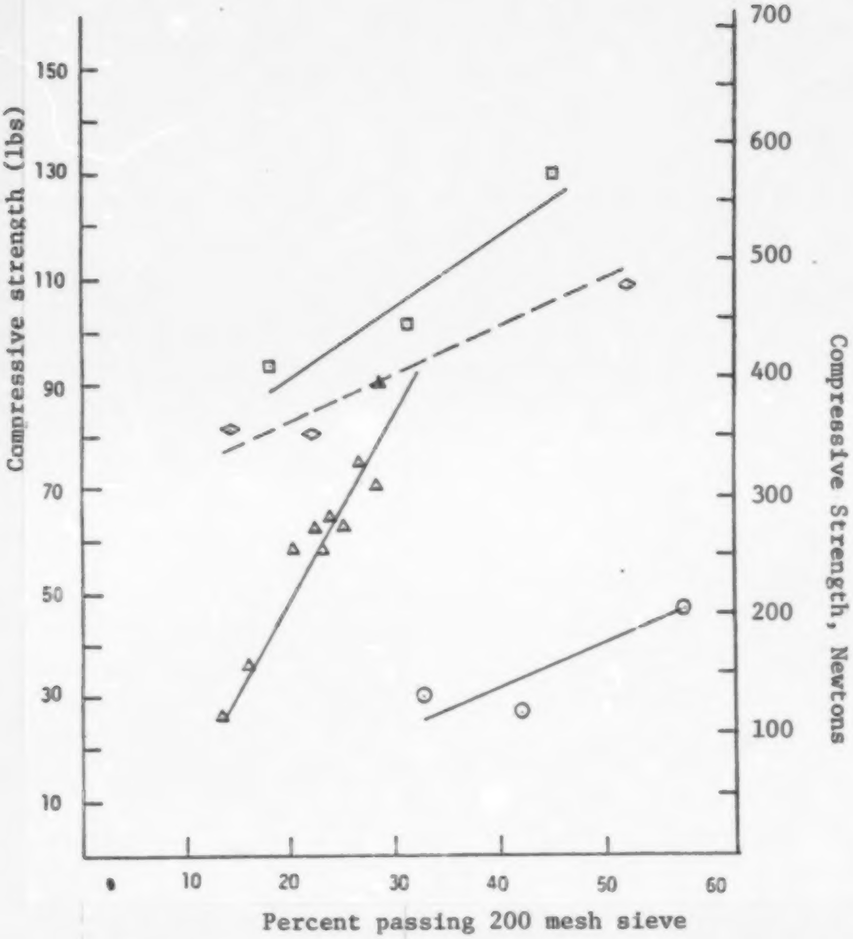

Figure A 1. Effect of particle size on pellet strength of various glass batches (Columbia Gas data).

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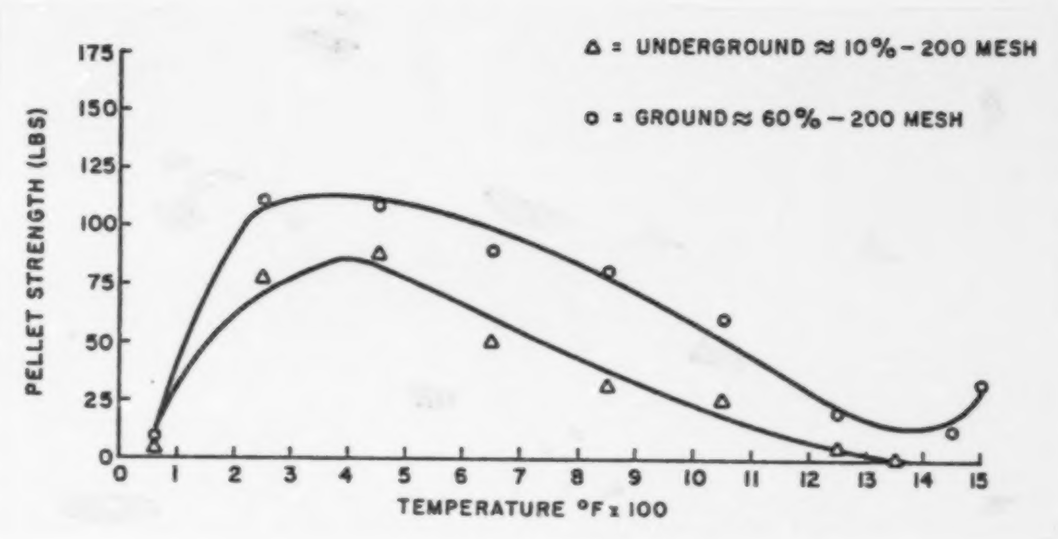

Figure A 2. Room temperature pellet strength after the pellets have been heated to various temperatures (Columbia Gas data).

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Some of the findings of the Columbia Gas studies that dealt with raw materials and that were specifically mentioned were:

1. Burned dolomitic limestones substituted in part for regular limestones were generally satisfactory as a binder. Substitutions of 25 to 100 percent, on an oxide basis, indicated that 50 percent substitution was more than satisfactory and could normally be less.
2. Preliminary evaluation of a single high calcium burned limestone indicated that it provided unsatisfactory strength to green pellets. Further evaluations of burned limestones from different geologic sources was not done but was recommended.
3. Grinding studies of individual raw materials and of whole glass batches were conducted. Grinding of the entire glass batch in an open circuit continuous ball mill was done satisfactorily, producing a particle size distribution similar to that discussed earlier.
4. Grinding of all batch components together was preferred over dry-mixing of size materials, although no significant differences were noted.
5. Except for limestone, raw material source did not seem to affect pellet strength.
6. At least 20 percent of the silica should pass a 200 mesh sieve.

Pelletizing

Pelletizing was found by to be the economically preferred method of consolidating glass batch by Columbia Gas. Various types of pelletizing equipment were evaluated. These included the Dravo shallow disc, the KVS cone, the Eirich deep pan, and the Stirling sintering drum. The characteristics of each were examined and the deep-pan type of pelletizer was judged superior in performance, although the cone-type also produced pellets with satisfactory properties. However, the cone was more sensitive to small changes in operating parameters.

Pelletizing was found to be more of an art than a science. Each glass batch had to be evaluated separately for its particular pelletizing characteristics on a specific pelletizer. The kinetics of pellet growth were found to be sensitive to moisture content and specific surface area of the powder being pelletized. It was reported that:

1. The fineness of the water spray must be changed with the particle size of the raw materials.

2. A residence time in the pelletizer of 5 minutes is desirable.

3. The particle size of the raw materials should not exceed 50 mesh.

4. Pelletizers of larger size provide pellets with improved properties.

5. The angle of inclination of the pan to the vertical should be between 45 and 60 degrees.

6. The height of the pan should be no less than 0.2 D (diameter of pan).

7. The surface tension of the water used should exceed 55 to 60 ergs for good pelletization.

8. Water should be sprayed with high speed where nodules pass through the spray area and where the probability is highest that nodules of all diameters will be hit by the spray.

9. The proportion of water to feed material must be kept constant.

Operating characteristics of three pelletizers evaluated by Columbia Gas are listed in Table A-1.

Significant experience was obtained with the Eirich deep-pan pelletizer (TR-21 model, 99 cm diam x 49 cm deep) revolving at 23 rpm. Pan angle was 60 degrees from the vertical. Glass batch was fed with a vibratory feeder. Approximately 22,700 kg of a ground-glass batch was pelletized in the TR-21. Pellets of a constant size (±0.6 cm) could be continuously produced. The pelletizer output could be varied from 180 to 910 kg/hr with no significant change in pelletizer performance nor drop in pellet properties. The Eirich pelletizer, like others, is commercially available in sizes up to 43 meters in diameter, and having a capacity to pelletize glass batch of 45,000 kg/hr.

Pellets were generally evaluated for their size, percent moisture, compressive strength, density, and drop strength. Wet pellet strength varied between 18 and 40 N for a 1.3 cm diameter pellet. Bulk density varied between 1.2 and 1.4 g/cc, and percent moisture between 7 and 12.

TABLE A-1. PELLETIZER OPERATING CHARACTERISTICS (COLUMBIA GAS DATA)

Item	Shallow bed disc	Cone	Deep bed disc
Pan diameter (cm)	99	122	100
Pan depth (cm)	13	76(1)	48
Speed (rpm)(2)	15	32	23
Slope (pan angle)	45°	27°	60°
Feed rate (kg/hr)	225-320	225-320	225-900
Width of feed path (cm)	20	10	8
Feed position	9 O'clock	7 O'clock	5 O'clock
Position - water spray	10 O'clock	8 O'clock	5 O'clock
Shape of water spray	Fan	Fan	Fan
Lining(3)	Steel	Concrete	Steel
Average pellet moisture (%)	12.5	11	9

(1) Measured along the cone wall.

(2) All pelletizers rotate clockwise.

(3) A layer of batch buildup on all linings.

The parameters identified which affect the pelletizing process are:

- Size of water spray,
- Position of water spray,
- Uniformity or consistency of water spray,
- Temperature of water,
- Rate or amount of water addition,
- Location of batch feed,
- Particle size of batch,
- Batch feed rate,
- Pellet bed temperature,
- Pelletizer rotational speed,
- Angle or tilt of pelletizer, and
- Retention time of pellets in pelletizer.

Many of these parameters are interrelated and cannot be evaluated independently. Good operating conditions were usually found by trial and error.

Important pelletizer control measures which were identified included:

- Water Control (flow location, temperature, and spray size and shape),
- Pelletizer (rotational speed and angle), and
- Batch control (amount and location).

The most critical handling period for pellets is while they are still wet, before drying. In general, pellets are the weakest at this time. The wet or as-formed strengths varied from 0 to 44 N for pellets made from typical container soda-lime batch. It was found that strengths of 23 N or higher produced a pellet of satisfactory handleability. The effect of fine raw materials on wet-pellet strength is illustrated in Figure A-3.

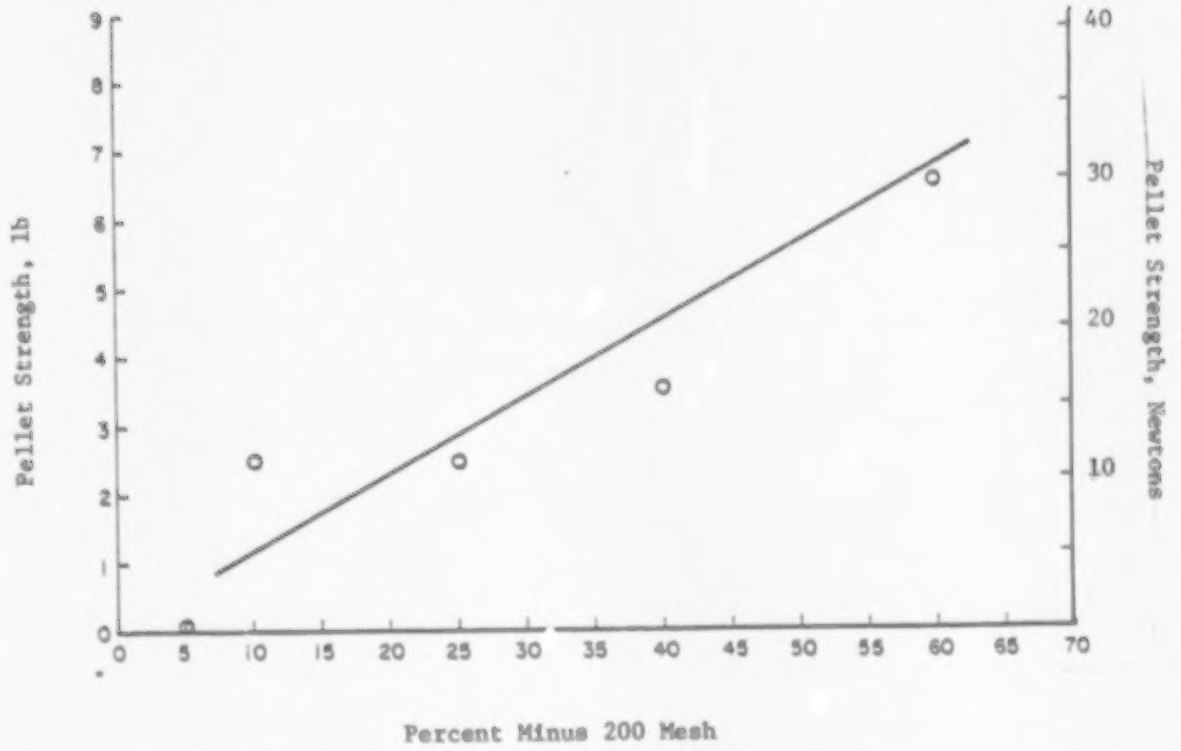

Figure A 3. Wet pellet strength versus batch particle size for a typical container glass batch (Columbia Gas data).

The data reported by Columbia Gas generally showed that the handleability of wet pellets could be related to their wet strength, when pellets are made in larger pelletizers. The general guidelines developed were:

Pellet Strength	Handleability
14 N	Pellets will crush or crumble with any contact.
14 N - 23 N	Pellets will deform if dropped or any load is placed on them.
23 N - 31 N	Pellets can be conveyed and dropped up to 0.61 meters normal handling.
31 N	Pellets will stand rougher than normal handling.

Drying and Preheating

Both bench-scale and pilot-scale drying and preheating experiments were conducted. Bench-scale testing was done under static gas-flow conditions in small ovens, and in a small fixed-bed preheater with combustion gases flowing through the pellet bed. Limited pilot scale testing was done in a 46 cm diameter moving-bed, vertical shaft furnace.

Drying Experiments--

Drying tests were conducted in both a smaller fixed-bed furnace and a larger moving-bed furnace. The fixed-bed was a chamber (30 cm diameter x 61 cm high) into which a stainless steel basket filled with wet pellets could be placed and hot combustion gases passed up through the pellets at a controlled rate.

In previous work conducted for Columbia Gas in the late 1960's pelletized glass batch was dried in a moving-bed drier at varying rates and temperatures up to 260°C. In bench-scale tests on pellets made from various batch compositions and having a range of particle-size distributions, drying was rather perfunctory. No problems were experienced, and drying could be accomplished at high rates. In the pilot phase of the preheating program, the drying rate of pellets was limited. Small parts of an outer layer would pop off if the pellet was dried rapidly. This phenomena was an unexpected development and experiments basically demonstrated that, if the pellets were exposed to a temperature above 180°C, popping was observed. The maximum continuous drying rate achieved was 182 kg/hr of dry pellets at an inlet gas temperature of 200°C and a wind to pellet mass ratio of 3.2. This drying problem was obviously related to the chemical or physical characteristics of this particular batch. It was deduced that the finer particle size of these raw materials, which were ground by an impact mill, especially the soda ash and limestone, caused the phenomena. A full understanding was not pursued because of the tight time schedule of this program. There appears to be a particle size range within which the glass batch raw materials should lie and this was identified as an area needing further definition.

The drying rate ranged from a blow ratio of 2.5-3.5 kg of hot gas for each kg of pellets. At these ratios, temperature was found to be a much more significant variable than the gas velocity.

Preheating--

The reason for examining drying and preheating was to reduce the uncertainty associated with building a prototype facility, which Columbia Gas hoped to do. Glass batch had not been continuously preheated to 760°C and above in a moving-bed shaft furnace. The Columbia Gas program determined some preheater design information and investigated process limitations relative to drying and preheating pelletized glass batch in a shaft furnace. A number of drying runs were conducted at various temperatures and blow ratios. The emphasis was on preheating. This included preheating to approximately 540°, 650°, and 760°C at discharge rates of about 90, 180, and 270 kg/hr. Pellet diameter was approximately 1.3 to 1.6 cm. One test was conducted up to 840°C to evaluate the upper preheating limit before sticking of pellets occurred. The sequence of these tests provided enough variation in operating conditions to allow the mechanisms of energy transfer between the pellets and the gas stream to be examined. It also permitted the pressure drop across the bed to be determined, thereby allowing the power requirements for larger systems to be estimated.

The test program did show temperature-distribution and pellet-flow problems, which need to be addressed in the design of larger operating units. The thermal efficiency in this smaller shaft ranged from 55 to 70 percent. This was believed to be good, considering the high surface area to volume ratio and the shorter height of this pellet bed. The power requirements, as related to the resistance of the moving bed to gas flow, were significantly below that determined previously for fixed-bed experiments at the same Reynolds numbers, although the moving-bed coefficient followed a curve parallel to that of the fixed bed.

The heat capacities of both reacted and fresh pellets were determined as a function of temperature in fixed-bed experiments. These ranged from approximately 0.275 to 0.450 Btu/lb/F.

A general energy balance was possible with the results of the moving-bed tests. This permitted a determination of how the Nusselt numbers (Nu) varied with changes in the Reynolds number

(Re) and the derivation of the following equations that permit the calculation of the pellet bed height and pressure drop for preheaters. These are:

$$L = \frac{1}{B(K-1)} \ln \frac{Tpo + \frac{Tgi - K\,Tpo}{K-1}}{Tpi + \frac{Tgi - K\,Tpo}{K-1}}$$

Where

L = Bed height.

K = Ratio of mass flow rates and specific heat of pellets to gases.

B = Ratio of the volumetric heat-transfer coefficient and cross sectional area to the pellet mass-flow rate and specific heat.

Tpo = Outlet pellet temperature.

Tgo = Outlet gas temperature.

Tpi = Inlet pellet temperature.

Tgi = Inlet gas temperature.

$$HL = \frac{L}{D\rho} \frac{\rho V^2}{2g}$$

Where

HL = Expected pressure drop.

f = Coefficient of resistance.

D = Mean pellet diameter.

ρ = Density of gas.

V = Gas velocity.

g = Gravitational constant.

Data were obtained from the preheating tests to solve these two equations for a range of conditions which might be expected to exist in a preheater.

Additionally, it was found that preheating data on pellets, determined at the bench-scale level, correlated well with the results observed in the shaft furnace. Hot pellet strength, weight loss, and density were all found to be similar in nature between the two types of experiments. For instance, if pellet strength and attrition loss was found satisfactory in the bench-scale tests, it was also suitable for the moving-bed tests.

Pellet strength was found to decrease as the temperature was raised above 540°C, or if the residence time was increased. For the glass batch tested in the pilot program, the 1.3 cm pellet strength dropped to a minimum of 88 N. Temperature was much more important than residence time, since the drop in strength was only about 30 percent, with a four-fold increase in residence time. It was determined that hot-pellet strength could be as low as 18 N; however, this only occurred with one test run in which a coarse (regular unground) batch was used. With this run, fine material that had attrited from the weaker pellets badly plugged the moving bed. At higher temperatures (above 760°C), many pellets had a glassy-looking surface and had cold strengths exceeding 775 N.

When heated, the initial strength of the pellets decreased as the hydrate bonds degraded. With finer materials, solid-state bonds begin to form as low as 430°C and provide strength to the pellet above 600°C. A detailed study of the reactions occurring during preheating was conducted on soda-lime glass batch. This study positively showed the presence of reaction products which bonded individual grains together, as shown in Figure A-4. These studies also indicated the importance of the particle size of the raw materials to pellet preheat strength.

Pellet strength determines the maximum preheat temperature. Pellets made from regular unground batch were generally found to have a maximum preheat temperature of about 600°C. Pellets made from batch containing finer materials could be expected to be heated to a temperature of 760°C. All pellets required a minimum cold strength of 23 N after heating to any temperature in order to be processed through a shaft furnace. Since the pellet strengths will vary plus or minus 39 N, an average strength of 62 N is desired.

For best strength and handleability characteristics, it was recommended that the pellets be heated to a maximum in the shaft furnace and then the temperature be decreased slightly before they are discharged from the furnace. The higher temperature causes more glass phases to form, which when cooled solidify and produce a stronger pellet. Strength increase by this approach is shown in Figure A-5 for a typical soda-lime batch.

Pilot Scale Program--

After laboratory work on pelletizing, drying, and preheating was completed, a pilot scale program was initiated. Glass batch was ground commercially in am impact mill, bagged, shipped, and then transferred to 55 gallon drums at Columbia Gas' facilities. The ground glass batch was pelletized in the TR-21 Eirich pelletizer,

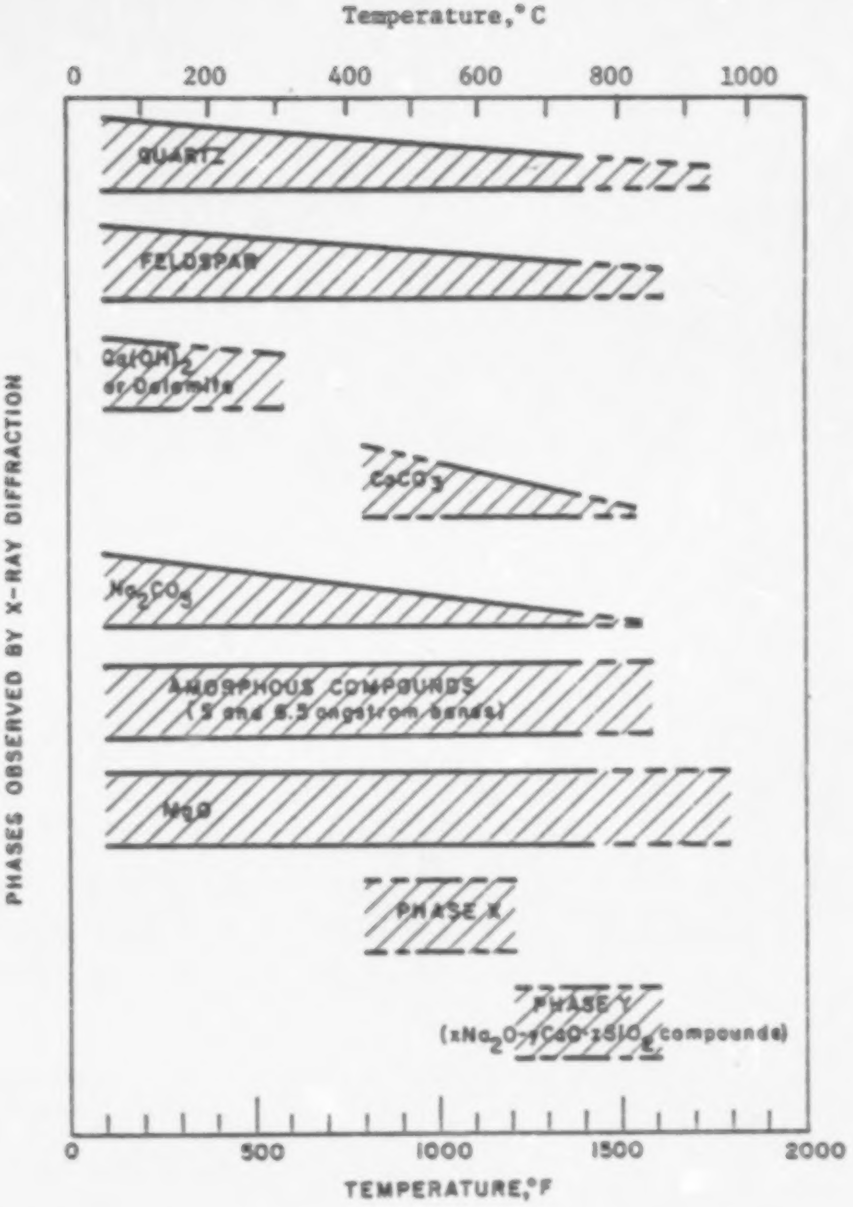

Figure A 4. Phases or compounds formed in a typical soda lime batch at various temperatures (Columbia Gas data).

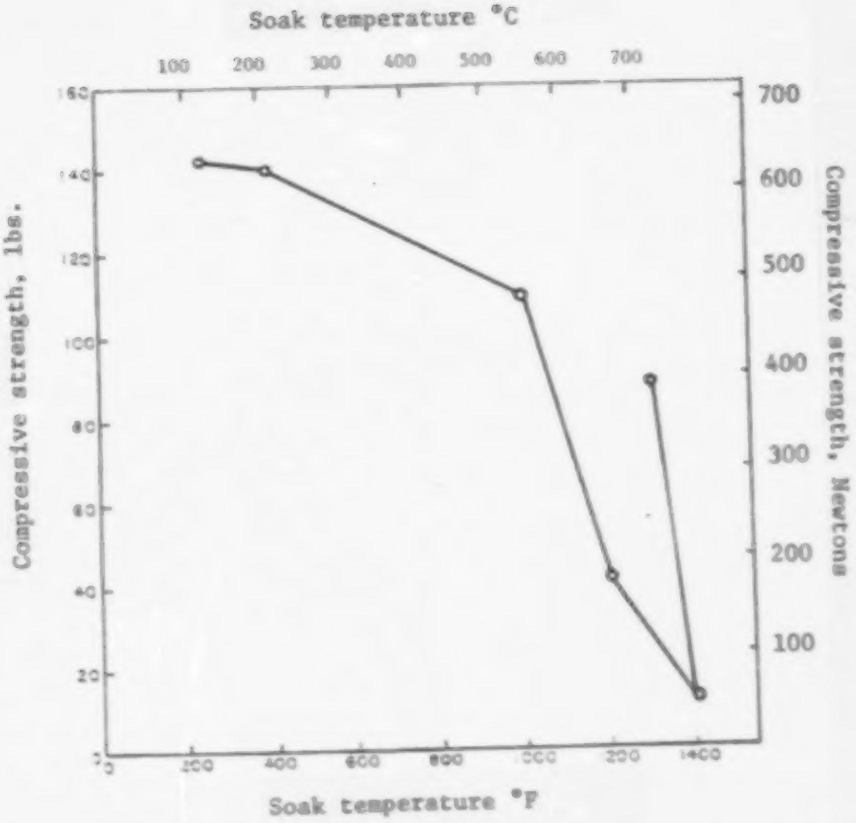

Figure A 5. Room temperature strengths of pellets which had been treated to various temperatures. The 1300°F strength was obtained by heating the pellets to 1400°F then lowering the temperatures to 1300°F. (Columbia Gas data).

dried, and preheated continuously in a vertical-shaft preheater, at a rate which varied from 90 to 270 kg/hr. The purpose of the pilot program was to obtain design information on drying and preheating in a moving-bed shaft furnace. The program was to support the design and operation of a larger pilot demonstration (80,000 kg/day) on a regenerative glass-melting furnace. This larger demonstration never materialized and the program was abandoned. The pilot work in Columbia Gas' laboratories did successfully accomplish its objectives of demonstrating that a soda-lime glass-batch composition can be dried and preheated to 820°C in a vertical-shaft furnace.

Figure A-6 is a schematic of the equipment layout used by Columbia Gas. The operation consisted of taking the loose ground-glass batch and feeding it to the pelletizer. Wet pellets were discharged over the lip of the pelletizer, then they rolled down a trough onto a conveyor, where they were taken to a small surge hopper at the top of the shaft furnace. The pellets passed down through the shaft where they were heated by the countercurrent flow of hot gases from the combustion,chamber. The hot pellets were discharged through a rotary air lock onto a metal belt conveyor and transferred to a 55 gallon storage drum.

The shaft was used to conduct both drying and preheating experiments. Temperatures were measured with thermocouples located along the centerline and walls of the shaft. Temperature profiles across the shaft were monitored in the region where the combustion products entered the bed. A thermocouple was used to measure the exit-gas temperature. Pressure was measured near the pellet discharge and inlet points, and where the combustion gases entered the bed. The air and gas flow were also measured. The mechanism for controlling the pellet-discharge rate was calibrated and frequently checked. Dew point of the exit gases was measured and provisions were made to increase, on occasion, the water vapor content of the combustion gases.

Crucible melt evaluations were conducted to determine the effects of pelletizing and preheating on melting and fining rates. Pellets made from finer materials melted about eight times faster than did a conventional loose batch at 1430°C. For equal time periods, the finely ground pelletized batches could be melted and fined 50 to 100°C below the temperatures required for a conventional batch. Approximately the same results were obtained with pellets that had been preheated as with dried pellets.

SODA-LIME GLASS INDUSTRY REVIEW

Soda-lime glass represents the largest tonnage of any glass composition that is produced by the U.S. glass industry. This composition is used to produce products in the container (SIC-3221), flat (SIC-3211), and pressed and blown (SIC-3229) glass industries. It accounts for 100 percent of the production in both container

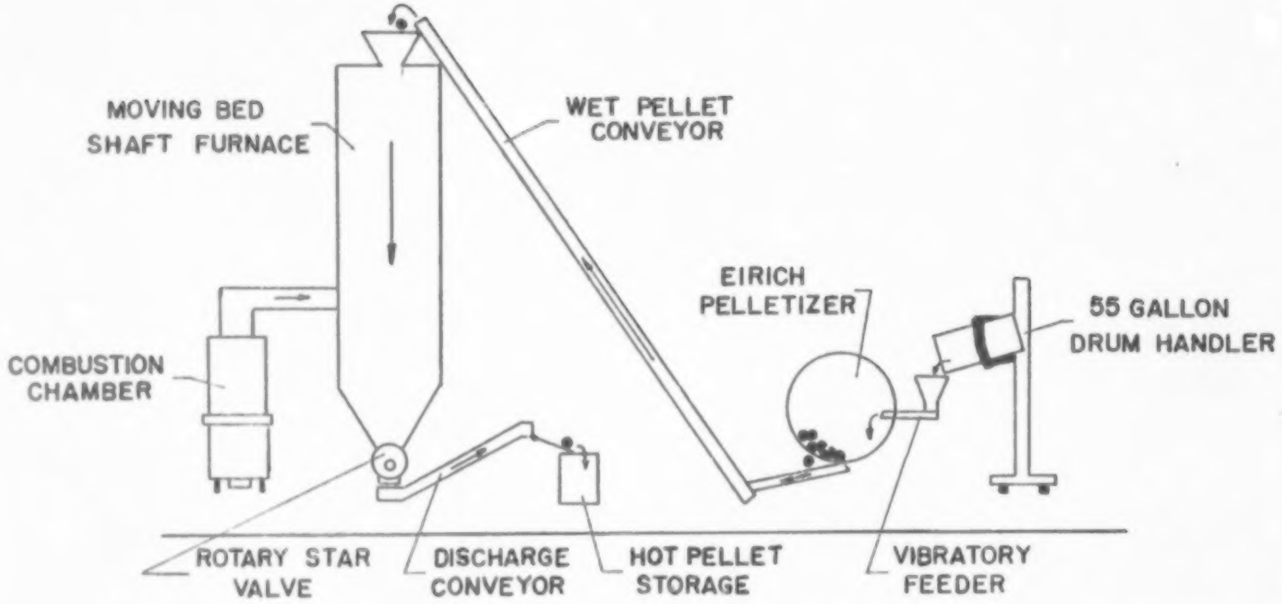
MOVING BED
SHAFT FURNACE
WET PELLET
CONVEYOR
EIRICH
PELLETIZER
55 GALLON
DRUM HANDLER
COMBUSTION
CHAMBER
ROTARY STAR
VALVE
DISCHARGE
CONVEYOR
HOT PELLET
STORAGE
VIBRATORY
FEEDER

Figure A 6. Schematic of pilot-plant process (Columbis Gas data).

and flat-glass industries, which produce an annual output of 11.9 and 2.7 million tons respectively. Soda-lime composition also accounts for 77 percent of the production in the pressed and blown glass industry--more than 1.6 million tons of annual production. Therefore, the total annual production of soda-lime glass is currently in excess of 16 million tons. The pressed and blown and flat-glass industries produce only clear soda-lime compositions, whereas the container glass industry produces both a clear and an amber composition in the proportions that are shown in Figure A-7. The energy that is required to maintain the annual production of soda-lime glass is approximately 19 percent of the annual energy usage for the stone, clay, and glass (SIC-32) industry. The flat and container glass industries require approximately 26 million and 13 million Btu's per ton of output, respectively. The pressed and blown glass industry is expected to have an energy efficiency that is no better than that of the glass container industry.

Geographic Distribution

The glass container industry has historically located its plants near the local markets to minimize the transportation costs involved in delivering the final product. This industry is comprised of 27 companies that operate 120 manufacturing facilities that are concentrated in the East, North Central, and Middle Atlantic census regions. A listing of these companies and the number of manufacturing facilities that they operate can be seen in Table A-2, and a distribution of the manufacturing facilities is presented in Figure A-8.

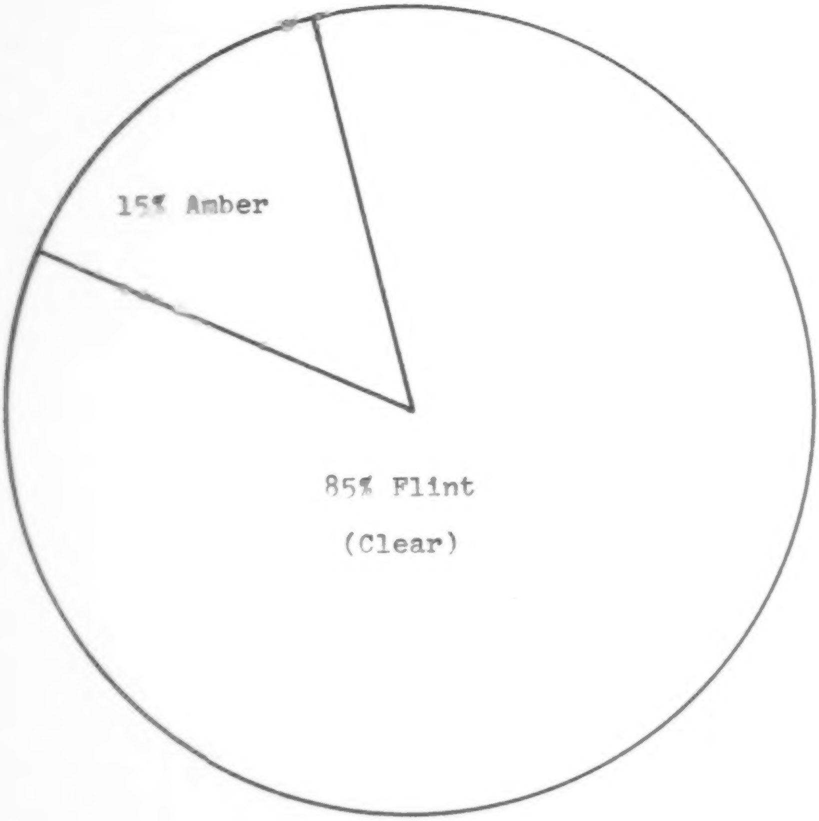

Figure A 7. Approximate distribution of the types of container glass (1976).

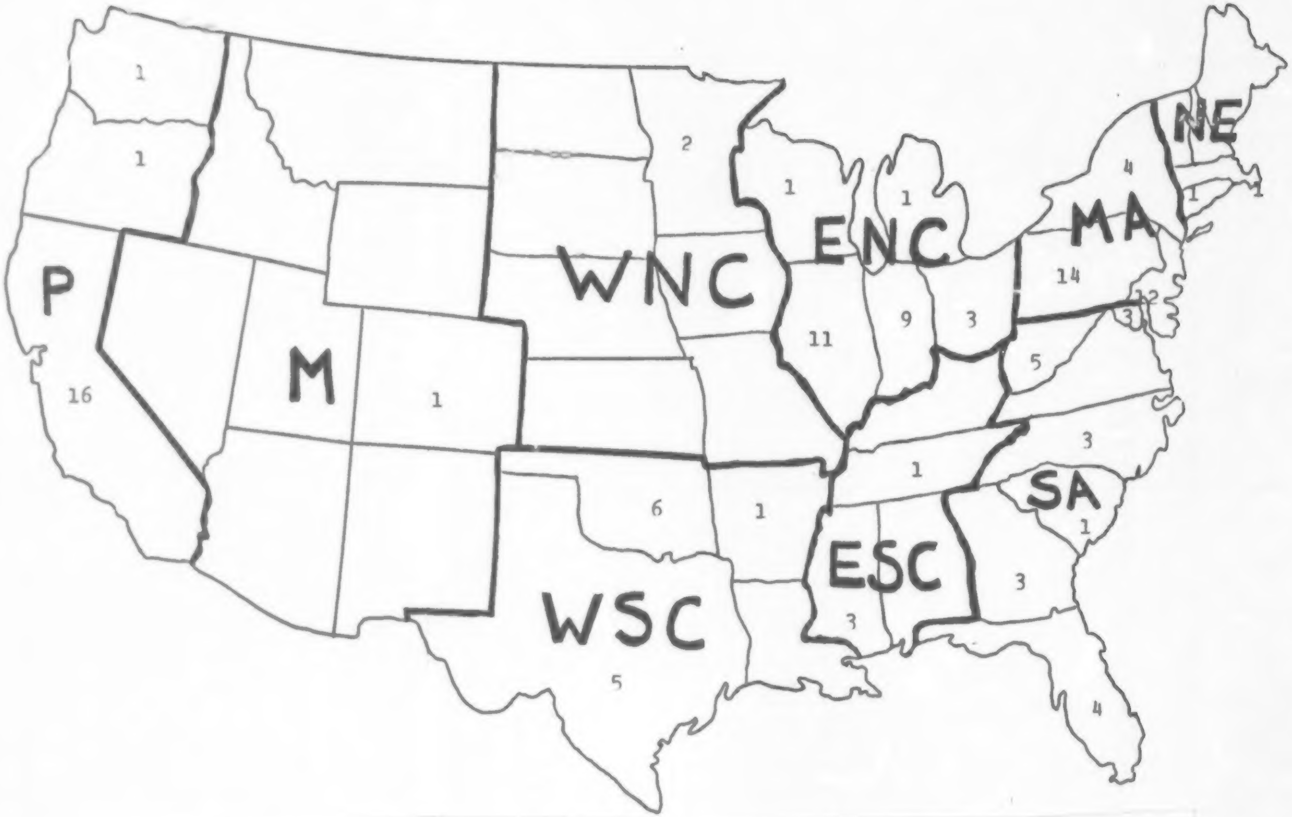
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FIGURE A.8 REGIONAL DISTRIBUTION OF GLASS CONTAINER MANUFACTURERS

TABLE A-2. MAJOR GLASS-CONTAINER MANUFACTURERS IN THE UNITED STATES[a]

Manufacturer	No. of plants	Manufacturer	No. of plants
Anchor Hocking	9	Latchford Glass	1
Arkanses Glass	1	Leone Industries	2
Ball Corporation	4	Liberty Glass	1
Bartlett Collins	1	Madera Glass Co.	1
Brockway Glass	14	Metro Glass	4
Chattanooga Glass	7	Midland Glass	4
Columbia Glass	1	National Bottle Corp.	4
Diamond Glass	1	National Can	4
Gallo Glass	1	Owens-Illinois	20
Glass Containers Corp.	12	Thatcher Glass	6
Glenshaw Glass	2	Underwood Glass	1
Hillsboro Glass	1	Wheaton Glass	2
Indian Head	7		
Industrial Glass	1		
Kerr Glass	7		

(a) Source: Material provided from GPI, dated October 24, 1975

The flat-glass manufacturing industry is comprised of 7 manufacturers who operate 31 plants in the United States. These plants are concentrated in Ohio, Tennessee, Pennsylvania, and California. The 7 flat-glass manufacturers are: PPG Industries, Libbey-Owens-Ford Company, Ford Motor Company, ASG Industries, Guardian Industries Corporation, C-E Glass, and Fourco Glass Company. The distribution of the flat-glass manufacturing facilities is shown in Figure A-9.

The pressed and blown glass industry is the most diverse of the 3 major glass manufacturing segments of SIC-32. As can be seen in Table A-3, this industry is comprised of many manufacturers who operate a total of 155 plants, which range from those that are fully automated to those that produce glass by manual methods that have changed very little over the centuries. The pressed and blown glass industry is concentrated in the East, North-Central, and Middle-Atlantic census regions, as is illustrated in Figure A-10. Approximately one-fourth of those plants that are shown in Figure A-10 do not produce a soda-lime glass composition.

Glass Composition

The soda-lime glass composition is one of the least complicated glasses, consisting mostly of SiO_2, Na_2O, K_2O, CaO, MgO, Al_2O_3, and Fe_2O_3. Although this list provides a general overview of the oxides that form the soda-lime glass composition, some major differences between the soda-lime produced by the various industries do exist. The major difference lies in the soda-lime glass that is produced by the flat-glass industry, which comprises 90 to 93 percent of the U.S. flat-glass production. This composition has no alumina because it is not required for the manufacturing process. Also, the flat-glass soda-lime has a slightly higher Fe_2O_3 content to impart the characteristic green color to window glass.

Another noticeable difference in the oxide composition is the higher Fe_2O_3 content of amber containers. The higher than normal concentration of this oxide is required to produce the dark amber color that is common in beer bottles.

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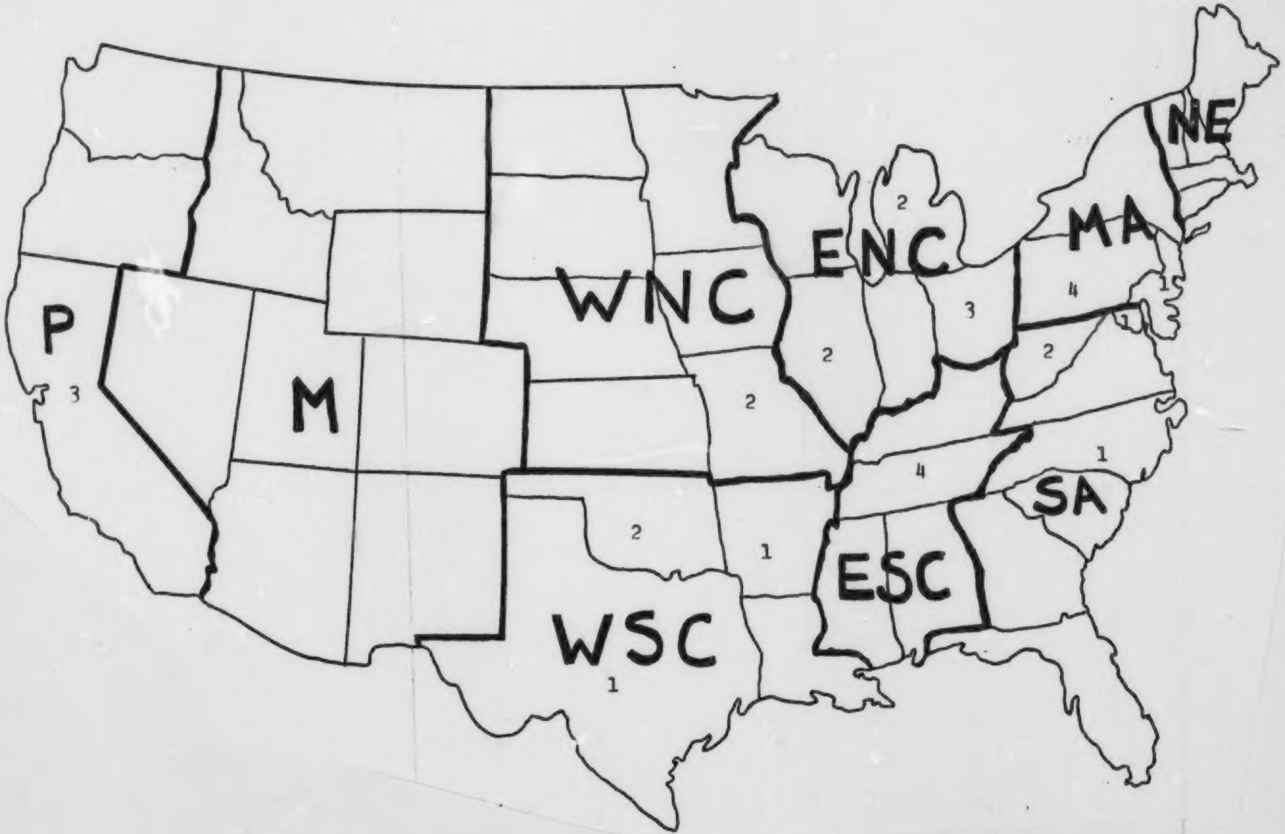
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FIGURE A.9 REGIONAL DISTRIBUTION OF FLAT-GLASS MANUFACTURERS

TABLE A-3. MAJOR PRESSED AND BLOWN GLASSWARE MANUFACTURERS IN THE UNITED STATES

Manufacturer	No. of plants	Manufacturer	No. of plants
American Optical	3	Hamon Handcrafted Glass	1
Anchor Hocking	4	Harvey Ind.	1
Arrowhead Puritas	1	Holophane	1
Atlantic Optical Moulding	1	Houze Glass Corporation	1
B and J Optical	1	Imperial Glass Corp.	1
Bartlett-Colline	1	Indiana Glass Corp.	1
Bausch and Lomb	1	Industrial Glass & Plastics	1
Beaumont Company	1	Interpace Corporation	1
Big Pin Glass Company	1	Jeanette Corporation	1
Blenko Glass Company	1	Jeanette Shade & Novelty Co.	1
Brock Glass Company	1	Johnson Glass	1
Brockway Glass	2	Kanawa Glass Company	1
E.O. Brody Company	1	Kapp Glass, Inc.	1
Cambridge Glass	1	Kaufman Glass Company	1
Canton Glass	1	Kessler, Inc.	1
Cataphote	1	King Seeley Thermos Co.	2
Champion Agate Company	1	Labino Glass Laboratories	1
Chemglass, Inc.	1	Lancaster Glass Corporation	1
Corning Glass Works	14	Lenox Crystal	1
Crescent Glass Company	1	Lewis County Glass	1
Crystal Art Glass	1	Louie Glass Company	1
Davis-Lynch Glass Company	1	Marble King	1
EMC Glass Corporation	1	Masden Ind.	1
Eastman Kodak Company	1	Mayflower Glass	1
Emerson and Cuming	1	Mid-Atlantic	1
Elite, Company, Inc.	1	J. H. Millstein	1
Erie Glass Mfg Company	1	Minners	1
Erskine Glass & Mfg.	1	Multicolor Glass	1
Federal Glass Company	1	Nuclear-Pacific	1
Fenton Art Glass	1	Overmyer-Perram	1
Fischer and Porter Company	2	Owens-Illinois	10
Fostoria Art Glass	1	Pacific Glass Works	1
Friedrich and Dimmock, Inc.	1	Peltier Glass Company	1
GTE Sylvania, Inc.	4	Penbarthy Electromelt Int'l	1
General Electric	9	Pennsboro Glass Company	1
Gentile Glass Company	1	Phoenix Glass Company	1
Gillinder Brothers	1	Pikes Peak Glass Company	1
Gladding-Vitro-Agate Co.	1	Piligrim Glass Corp.	1
Glass Works, Inc.	1	Pittsburgh Corning Corp.	2
Guernsey Glass Company	1	Pope Scientific, Inc.	1
Haley Glass Company	1	Potter Industry, Inc.	4

(continued)

TABLE A-3. (Continued)

Manufacturer	No. of plants	Manufacturer	No. of plants
RCA Corp.	1	Super Glass Corporation	1
Rainbow Art Glass	1	Swift Glass Corporation	1
Ray-Lite Glass, Inc.	1	Techniglass, Inc.	1
Reha Glass Company	1	Thermal American Fused Quartz	1
Rocky Mountain	1	Thomas Ind Inc.	1
Rodifer Gleason Glass Corp.	1	Variety Glass Inc.	1
St. Clair Glass Works	1	Venejian Art Glass	1
Scandia Glass Works	1	Victory Glass Company	1
Schott Optical Glass Co.	1	Viking Glass Company	1
Scott Depot Glass Company	1	W Virginia Glass Specialty Co.	1
Sellstrom Mfg.	1	Westington Electric Corp.	2
Earl Shelly Glass Company	1	Westmoreland Glass Company	1
Sinclair Glass	1	Wheaton Ind.	1
L. E. Smith Glass Company	1	The Paul Wissmach Co, Inc.	1

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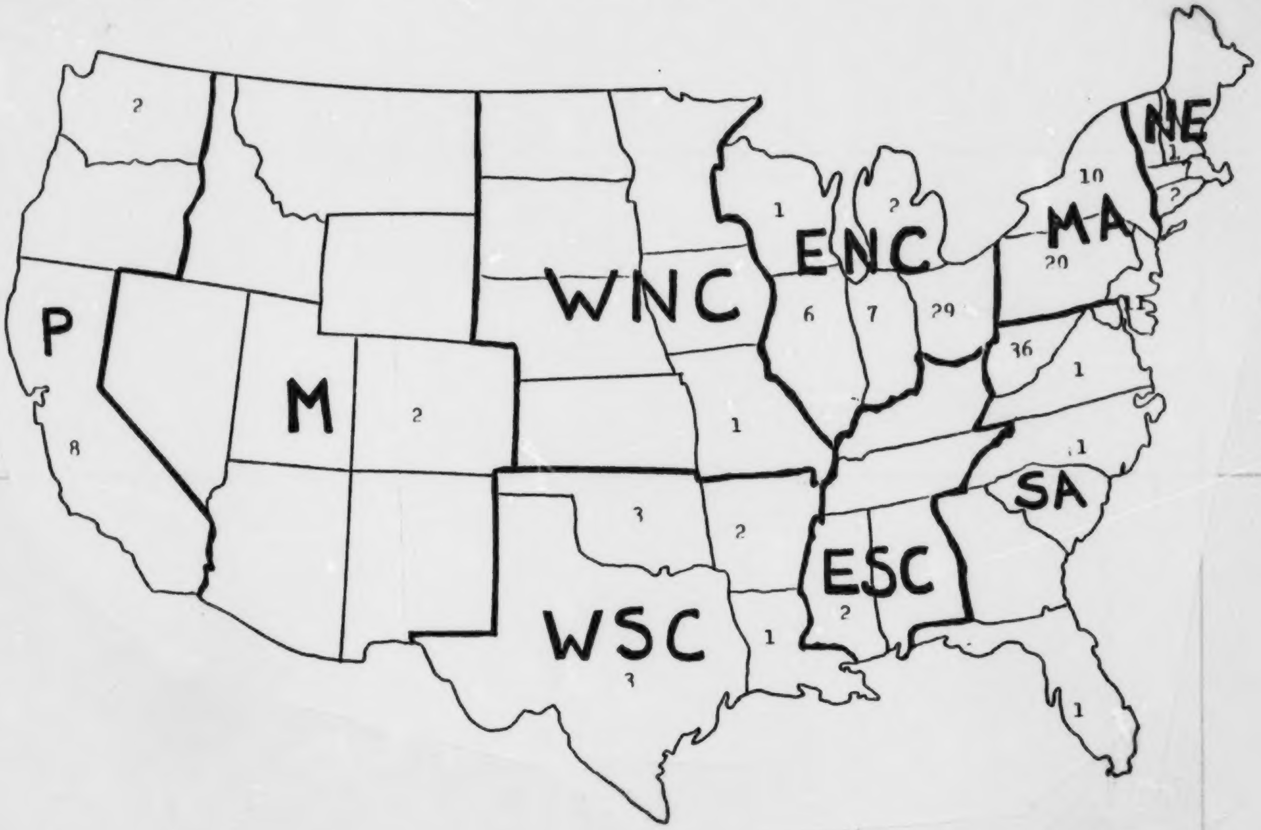
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FIGURE A.10 REGIONAL DISTRIBUTION OF PRESSED AND BLOWN GLASSWARE MANUFACTURERS

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Various other additives are included to produce properties that either are required by the final product or are beneficial in the production process. The majority of the additives are used to produce various colors in cosmetic containers and kitchen and tableware. A list of typical soda-lime glass compositions is shown in Table A-4.

TABLE A.4 TYPICAL SODA-LIME COMPOSITIONS IN WEIGHT PERCENT[a]

Industry	SiO_2	Na_2O	K_2O	CaO	MgO	Al_2O_3	Fe_2O_3
Container							
Clear	72.75	14.6	-	10.6	-	2.0	0.05
Amber	72.55	14.6	-	10.6	-	2.0	0.25
Flat	73.00	13.7	-	8.8	3.8	0.1	0.1
Pressed and blown	73.41	15.47	0.11	6.02	4.20	0.6	0.05

(a) Source: survey of manufacturers in the industry.

Raw Materials

The choices of raw materials that can be used for the production of soda-lime glass is limited. However, several factors such as distance to supply, requirements of the final product, cost, and availability influence the choice of materials that are used in any particular manufacturing plant. Also, past practices of the particular industry segment tend to influence the materials that are generally acceptable in that segment. Cullet and scrap glass are used in all three industry segments in amounts from 15 to 66 percent of the total input to the melting process. The ratio of cullet is determined by its availability, which is in turn determined by the efficiency of glass usage that is inherent with the production process.

The largest diversity of raw material sources is in the glass-container industry. The commonly used raw materials for the production of clear, soda-lime, container glass are shown in Table A-5. This table illustrates that several materials can be used to provide particular oxides to the glass. Aragonite, salt cake, and feldspar are the preferred materials on the list for the production of clear soda-lime glass. Gypsum, however, is gaining more acceptance as a raw material in this industry. For the production of amber glass containers, the raw material list is generally the same as that used for clear containers. However, as can be seen in Table A-6, pyrites are added to the list because they are used to develop the oxidation/reduction conditions that are required for production of the amber color.

TABLE A-5. TYPICAL CLEAR SODA-LIME CONTAINER GLASS

Raw materials	Percent of input	Primary oxide supplied
Sand	47	SiO_2
Soda ash	20	Na_2O
Aragonite [(a)]	13	CaO
Limestone [(a)]	17	CaO
Feldspar [(a)]	4.5	Al_2O_3
Aplite [(a)]	6	Al_2O_3
Salt cake [(a,b)]	0.7	Na_2O
Gypsum [(a,b)]	0.6	CaO
Carbon [(a,b)]	0.18	C
Calumite [(a,b)]	2.5	C
Cullet	18	SiO_2, Na_2O, K_2O, CaO, Al_2O_3

(a) Only one used in any given fill.
(b) Sulfate and reducing agents for refining.

TABLE A-6. TYPICAL AMBER SODA-LIME CONTAINER GLASS

Raw materials	Percent of input	Primary oxide supplied
Sand	30	SiO_2
Soda ash	10	Na_2O
Aragonite	9	CaO
Feldspar	4	Al_2O_3 Salt cake
Na_2O	0.4	
Carbon	0.9	C
Iron pyrites	0.14	FeO
Cullet	46	SiO_2, Na_2O, K_2O, CaO, Al_2O_3

TABLE A-7. TYPICAL SODA-LIME FLAT GLASS (a)

Raw Materials	Percent of input	Oxide supplied
Sand	19	SiO_2
Soda ash	18	Na_2O
Limestone	4	CaO
Dolomite	15	CaO, MgO
Salt cake	2	Na_2O, SO_3
Carbon	2	C
Rouge	0.03	Fe_2O_3
Cullet	40.0	SiO, Na_2O, CaO, MgO, Fe_2O_3

(a) Produced by float process.

The production of flat-glass products is generally accomplished with a list of raw materials similar to that shown in Table A-7. As has been previously noted, this glass product contains a higher than normal concentration of Fe_2O_3 which necessitates the addition of rouge to the raw material input. Also, the absence of alumina in the glass composition eliminates the need for feldspar or any other aluminim-bearing mineral. Dolomite is included as part of the input for the production of flat glass to provide MgO which imparts desirable forming characteristics.

The oxide composition of soda-lime tableware is very similar to that of soda-lime containers. Therefore, the raw materials that are used for the production of tableware are generally the same as those that are used for the production of glass containers. However, due to industry preferences, nepheline syenite is substituted for feldspar as the source of alumina. Oftentime, minerals such as feldspar are added to induce desirable forming properties. Table A-8 lists a typical set of raw materials for soda-lime tableware.

The raw material specifications are generally similar throughout all three segments of the glass manufacturing industry. The primary specification is one of material purity to prevent the production of glass with undesirable color. Another major raw material specification is grain size. This specification usually has two limits: (1) an upper limit to remove the very coarse fraction so that undesirable, unmelted, refractory grains are not left in the glass product and (2) a lower limit that specifies the fraction fine material to prevent dusting and carry-over during the batch handling and melting processes. Raw material suppliers form a limited list of organizations that are primarily engaged in the benefication of mineral products. Some typical specifications of various raw materials that are used for the production of soda-lime glass can be found in Tables A-9 through A-14.

TABLE A-8. TYPICAL SODA-LIME TABLEWARE GLASS

Raw material	Percent of input	Primary oxide supplied
Sand	56	SiO_2
Soda ash	20	Na_2O
Burnt lime	7	CaO
Nepheline syenite	2	Al_2O_3
Fluorspar	0.2	CaO
Salt cake	0.2	Na_2O
Carbon	0.2	C
Cullet	15	SiO_2, Na_2O, K_2O, CaO, Al_2O_3

TABLE A-9. SPECIFICATIONS OF SEVERAL GLASS-MELTING SANDS

Screen analysis cum.		Chemical analysis	
Screen	Percent	Oxide	Percent
20	Trace	SiO_2	99.65
30	1.7	Fe_2O_3	0.028
40	16.5	Al_2O_3	0.113
50	53.5	TiO_2	0.018
70	82.1	CaO	Trace
100	94.8	MgO	Trace
Pan	100.0	L.O.I.	0.190
20	None	SiO_2	99.70
30	1.2	Fe_2O_3	0.021
40	16.8	Al_2O_3	0.141
50	47.3	TiO_2	0.021
70	73.1	CaO	Trace
100	89.4	MgO	Trace
140	97.5	L.O.I.	0.113
Pan	100.0		
20	None	SiO_2	99.81
30	1.2	Fe_2O_3	0.025
40	10.4	Al_2O_3	0.125
50	42.8	TiO_2	0.020
70	83.5	CaO	Trace
100	95.0	MgO	Trace
Pan	100.0	L.O.I.	0.117
20	None	SiO_2	99.65
30	0.3	Fe_2O_3	0.023
40	3.7	Al_2O_3	0.341
50	15.0	TiO_2	0.019
70	44.8	CaO	Trace
100	81.9	Mgo	Trace
140	94.2	L.O.I.	0.172
200	97.6		
Pan	100.0		

(continued)

TABLE A-9. (Continued)

Screen analysis cum.		Chemical analysis	
Screen	Percent	Oxide	Percent
20	None	SiO_2	99.70
30	1.3	Fe_2O_3	0.028
40	14.8	Al_2O_3	0.122
50	54.8	TiO_2	0.033
70	83.1	CaO	Trace
100	95.0	MgO	Trace
140	98.5	L.O.I.	0.117
Pan	100.0		
40	Trace	SiO_2	99.80
50	0.4	Fe_2O_3	0.018
70	5.9	Al_2O_3	0.093
100	48.5	TiO_2	0.011
140	85.3	CaO	0.010
200	98.6	MgO	Trace
Pan	100.0	L.O.I.	0.109
20	None	SiO_2	99.71
30	0.5	Fe_2O_3	0.019
40	5.4	Al_2O_3	0.108
50	23.0	TiO_2	0.012
70	55.7	CaO	Trace
100	84.0	MgO	Trace
140	96.4	L.O.I.	0.140
200	99.2		
Pan	100.0		

TABLE A-10. TYPICAL SPECIFICATIONS FOR SODA ASH

Chemical analysis	Percent by weight
Na_2CO_3	99.56
$NaHCO_3$	0.0
NaCl	0.25
Fe_2O_3	0.0017
Na_2SO_4	0.017
SiO_2	0.0019
Al_2O_3	0.0002
$CaCO_3$	0.011
$MgCO_3$	0.004
H_2O	0.16
Na_2O	58.22

Screen analysis

Mesh	Percent retained
20	1.1
40	55.5
60	31.1
80	8.4
100	2.4
140	1.0
200	0.5

TABLE A-11. TYPICAL SPECIFICATIONS FOR LIMESTONE

Chemical analysis	Percent by weight
H_2O	0.08
Loss on ignition	43.60
CaO	53.3
Al_2O_3	0.10
Fe_2O_3	0.05
SiO_2	0.25
MgO	0.40
Sulfates	Trace
TiO_2	0.00
$CaCO_3$	98.4
$MgCO_3$	1.76

Screen analysis

Mesh	Percent retained
8	0.00
12	1.7
16	8.2
20	16.1
60	44.6
120	18.0
Passing 120	11.4

TABLE A-12. TYPICAL SPECIFICATIONS OF DOLOMITE

Chemical analysis	Percent by weight
Loss on ignition	47.46
SO_2	0.22
Fe_2O_3	0.053
Al_2O_3	0.11
CaO	30.59
MgO	21.50
SO_3	0.032
P_2O_5	0.002

Screen analysis

Mesh	Percent retained
8	0.0
12	0.4
16	20.8
20	30.0
40	31.8
70	11.1
100	3.2
-100	2.7

TABLE A-13. TYPICAL SPECIFICATIONS FOR SALT CAKE

Chemical analysis	Percent by weight
Mg	0.024
MgO	0.04
Na_2SO_4	99.67
Zn	0.0008
Fe_2O_3	0.23
Insoluble	0.04

Screen analysis

Mesh	Percent retained
20	0.0
30	0.48
40	2.15
60	7.12
100	33.03
200	46.97
-200	10.25

TABLE A-14. TYPICAL SPECIFICATIONS OF A CARBON SOURCE

Chemical analysis	Percent by weight
Volatile loss	38.05
Moisture	1.98
Fixed carbon	57.03
Ash	4.92
Sulfur	1.26
Btu (dry)	14,340
Screen analysis	
Mesh	Percent retained
10	0.3
20	7.5
30	9.0
40	10.8
60	18.0
100	26.2
150	17.4
200	6.5
250	2.0
325	1.0
-325	0.5

LITERATURE SURVEY

A review of literature and patents was made. This review covered pertinent information on glass batch consolidation, preheating, and melting. A synopsis of the review is given here. The reference numbers refer to the literature and patents listed separately in a later section of this appendix. The literature was organized alphabetically by author and the patents numerically, with foreign patents at the end.

Other surveys need also be consulted in order to obtain a complete picture of all the relevant technology. These surveys include:

- Methods of Glass Batch Preparation, prepared for FMC Corporation by W. B. Pings in 1968.
- Methods of Glass Batch Preparation, Glass Melting, and Refining, prepared for Columbia Gas System by W. A. Hedden and C. W. Kistler, Jr., of Battelle's Columbus Laboratories in 1971.
- Air Pollution in Relation to Glass Manufacturing, prepared for FMC Corporation by W. B. Pings in 1968.

The focus of glass batch agglomeration has been primarily on pelletizing and briquetting. Preheating and presintering of the glass batch can add useful energy (sensible heat) into the furnace. Higher degrees of preheating will initiate the batch chemical reactions and reduce the glass melting energy requirements. Both phenomena are discussed in this review. Some melting studies of agglomerated, preheated, or prereacted glass batch have been reported and are also summarized. The significance of agglomerated glass batch for developing control technology which abates air pollution and conserves energy is also discussed.

Information was obtained from many sources, including Chemical Abstracts, Ceramic Abstracts, Glass Industry Magazine, and various other technical books and magazines found to have relevant information. The review included technical articles and books, reports, patents, and miscellaneous correspondence obtained primarily during the past 10 years.

Agglomerated Glass Batch

Many methods can be used to agglomerate glass batch, but the method that is chosen should produce the most benefits at the least cost. Much work has been done in the past 15 years in the agglomeration of glass batch and other materials. The emphasis for this study is on agglomerates which can be preheated, preferably by hot combustion products from the melting furnace. Most of the studies on agglomeration of glass batch have not dealt with preheating the raw materials.

Agglomeration methods can be broadly categorized as tableting, briquetting, extrusion, agitation, and heating(4). In each case, the individual particles are still identifiable after agglomeration. Pelletizing, which is discussed in detail, is an agitation process. Some other methods which have been applied to glass batch include extrusion and roll compaction. Extrusion is not particularly appealing because of wear on the die, auger, and housing. Roll compaction is a viable process for agglomeration, but the flakes produced from this method do not readily lend themselves to preheating by countercurrent flow. For economic reasons, most of the various methods for agglomerating materials can be eliminated when choosing a suitable process to agglomerate glass batch for preheating purposes. Only pelletizing and briquetting are believed viable and are considered in any detail.

Agglomeration of glass batch has been examined many times during the past 70 years. Commercially it has been practiced in Japan, and possibly in Russia and some European countries (24,38,42). A high interest in this technology appears to exist on the part of glass manufacturers in the United States (10). Many facets of glass-batch agglomeration must be considered if a process is to prove itself economical. Conditions which in the past may have prevented the successful implementation of an agglomeration process may no longer exist. Unfortunately, few tests have been run on production melters, making complete economic evaluation of the existing data difficult. Many benefits are cited in the literature and these include:

- Minimized demixing of the glass batch.
- Reduced dusting in the melters.
- Reduced carryover into regenerators.
- Reduced attack on refractory superstructure.
- Increased output.
- Lower operating temperatures in the melter.
- Increased thermal efficiency.
- More homogeneous glass.
- Improved plant working conditions.
- Reduced volatization from the melt surface.

The magnitude of each of these benefits depends upon the particular manufacturing operation.

One of the first attempts at agglomeration occurred in the late 1800's by a Russian researcher who made bricks from wet glass batch. He reported that the mixture melted several hours earlier than loose batch. Many other attempts at briquetting have been made in Russia, Germany, and the United States, and were outlined in an article by Knapp (24). He concluded that the high cost of briquetting equipment and the power needs always exceeded the advantages obtained by this form of agglomeration.

In 1935, a 19 week test of briquettes in a 68,000 kg/day (75 ton/day) melter was conducted by the Ford Motor Company. The test showed reduced carryover, less refractory wear in the regenerators and superstructure, a more homogeneous glass, and a 25 percent increase in production. Sodium silicate was used as a binder, and high wear on the briquetting rolls and iron contamination of the glass occurred. Overall, economics did not justify continuation.

Knapp (24) also describes the switch to pelletizers by Europeans in an effort to reduce agglomerating costs. In Europe, pelletizers are used extensively in the production of cement and for iron-ore roasting. Raw materials having a proper particle size can be fed into a pelletizer, and under the influence of the surface tension of the water, the materials agglomerate as the pelletizing pan revolves (much like a snowball). The pelletizer requires a minimum amount of energy and exhibits no wear or batch contamination. Not every glass batch can be pelletized, and a thorough understanding of pelletizing is needed to apply the concept so that the maximum benefits can be obtained.

Container glass batch was pelletized at a plant in the United States in 1964 (12). Results of this test showed a 6 percent reduction in fuel and reduced carryover. Shortly afterwards in 1965, pelletizing of glass batch was initiated by the Japanese (38) and four plants were operating in 1969. Benefits obtained by the Japanese included a substantial increase in production capacity at plants producing colored glass containers (from 118 to 163 x 10^3 kg/day) and flint glass (from 19 to 136 x 10^3 kg/day). Raw materials used in Japan are finer than those conventionally used by glass manufacturers in the United States, and caustic soda replaces part or all of the soda ash. All materials passed a 60-mesh sieve, with 30 percent of the particles finer than 150 mesh. Silica was ground at the mine site. The process was completely automated and pelletizers were monitored by closed-circuit TV.

Briquetting--

Briquetting machines consist of two rolls containing pillow-shaped cavities. These rolls are spaced below a hopper containing mixed glass batch such that raw materials fall into the cavities as the rolls turn. Briquettes can range in mass from a few grams to as much as 4.5 kg. Briquetting machines range in size from 45kg/hr to 45×10^3 kg/hr, and roll force can be as high as 2.6×10^6 N. A binder is usually needed to successfully briquette glass batch unless the batch is ground. Sodium silicate, caustic soda, and hydrated dolomitic limestone have been used as binders.

The most difficult problem associated with a roll-type briquetter is feeding the proper quantity of material into each of the rapidly rotating pockets in the roll. Contamination of the glass batch by the roll is another problem which has been reported. Briquetters also have high capital costs, high power costs, and high maintenance costs compared with pelletizing equipment; therefore, the suitability of briquetting machines to agglomerate glass batch is still questionable. The major advantages would be appear to be in the use of coarser materials for briquettes, but some question still exists as to the strengths of these briquettes during preheating.

The most recent experience, sponsored in part by FMC in conjunction with the Colorado School of Mines Research Institute (6), was a pilot plant facility operated by Ball Brothers Corporation in Muncie, Indiana, which used briquetted glass batch. In this test, the batch was wetted at 4-7 percent moisture for briquetting using a hydrated dolomitic limestone as a binder. Briquettes were heated up to 816°C (1500°F) and fed directly into a small pilot melter at rates up to 113 kg/hr. Decreases in fuel requirements of 25 to 42 percent were reported. Stack emissions were also decreased significantly. Similar results were found in 1972 by Fejer (11,11a) for briquettes fed to a frit melting furnace at the Ferro Corporation's plant in Cleveland, Ohio.

Overall, the costs of briquetting have generally been found to be uneconomical. There is little evidence to show that the situation has changed over the past 40 years.

Pelletizing--

Pelletizing is an agglomeration process whereby loose powders are compacted under the surface tension forces of water or other suitable liquid added to the pelletizing machine. Pelletizing is still an art and each group of materials can behave differently depending on their physical and chemical characteristics. Much of the experience in pelletizing of materials comes from the iron-ore industry where materials are pelletized for shaft furnace feeds before use in metallizing furnaces. Superior equipment or methods for pelletizing glass batch do not appear to be well established. Each depends upon the raw materials being utilized and the pellet quality desired. Pellets have been produced which contain 7 to 9 percent water with densities comparable to those reported for briquetted glass batch.

Pelletizing equipment is classified into discs, drums, and cones. Pelletizing drums require screening and recycling, and therefore are not as attractive as discs or cones. Pelletizing cones (manufactured by Kennedy Van Saun) appear to have operational difficulties resulting from a tendency for pellet size to cycle. Disc-type pelletizers are generally divided into shallow and deep pans. Important pelletizing parameters include pan or drum speed, pan angle, material and water feed rates, and material and water feed locations. Residence time in the pelletizer is another of the more important factors in determining pellet quality (1). Moisture content is also very important, because pellets are formed by collision or cohesion of particles encapsulated by a thin film of water. Capillary forces that hold this water film are also important in pellet formation.

Large commercial pelletizing systems became generally available in the 1960's, which resulted in much of the experimentation with the pelletizing of glass batch. Glass Container Industry Research Corporation (GCIRC) conducted tests at Castle Hanson Glass in 1965 (12) on a container glass batch that was pelletized on a shallow pan disc and the pellets fed directly into a melting furnace. Burned dolomite was used as a binder and the pellets were dried before melting. Fuel consumption was lowered 6 percent with pellets and dust carryover was greatly reduced. The raw materials were not ground. Pelletized glass batch was also made on a trial basis at Knox Glass by the Surface Combustion Company in 1969. Eight tons of pellets were fed into a 136,000 kg/day (150 ton/day) melting furnace with no noticeable effects on the glass quality or formability. Many different types of binders have been examined. The U.S. patent by Bair in 1945 (P-3) lists most of the common binders which might be considered in pelletizing glass batch. Yamamoto (P-20), in 1970, added caustic soda as an additional binder. Several other patents, Eirich (P-30), Pugh (P-18), and Kalousek (P-9), have also dealt with various types of binder systems. Engelleitner (10) has reviewed binders applied to glass batch materials. Pelletizing appears to be the most economical agglomeration process which can be used with glass batch when capital costs, operating costs, and maintenance costs are considered. The advantages and experiences related to pelletizing of glass batch are discussed in great detail by Knapp (24). One advantage for using pelletized glass batches is that finer raw materials can be used in the melter without dusting. Such materials can be melted and fined at significantly lower temperatures than conventional glass batch.

Preheating

Preheating of glass batch agglomerates is desirable for three major reasons:

- Improved overall thermal efficiency of the glass melting process by separately heating batch up to 850°C, utilizing waste heat from the melter where possible.
- Reduced volatilization and pollutants as a result of lowering melting temperatures and prereaction of batch materials.
- Faster and more uniform melting of new silicate compounds from batch prereaction than from conventional unground batch. Heat transfer into agglomerated batch is promoted over that obtained with loose batch.

About half of the theoretical energy needed to produce container glass from conventional glass-making raw materials is required to heat the raw materials up to 750°C. By preheating in a separate furnace and feeding hot agglomerates to the melting furnace, the theoretical energy needed in the melting furnace will be reduced considerably. Industry focus has been on moving-bed shaft furnaces because they typically have a thermal efficiency of 70 percent or higher, a desirable characteristic for preheating pellets. The energy for preheating can be supplied from the waste-gas products discharging from the conventional side port or end port regenerative furnaces in use today. Alternately, energy can be supplied by a separate combustion package.

Very little is known about the reactions which occur in an agglomerated glass batch at temperatures below 750°C. Studies have shown that the reactions are complex and depend upon a great many factors. Since these factors influence pellet strength, they are important. At low temperatures (drying temperatures), a bond is formed which is probably a complex hydrate with some possible carbonation also occurring. This bond breaks down slowly as pellets are heated until it is literally nonexistant above 550°C. Agglomerates will have little or no strength in the absence of a higher temperature bond caused by a solid state eutectic reaction between soda, lime, and silica bearing materials. This bond appears to be initiated by the formation of an amorphous silicate layer at the surface of silica grains. As reactions proceed, a monosilicate is formed at the silica reaction product interphase, probably by transportation of material across the reaction layer. This monosilicate and the amorphous silicate combine to form a disilicate. Also, evidence exists indicating the formation of a compound containing equal amounts of soda, lime, and silica. The formation of these silicates that provide bonding among materials in the agglomerate at higher temperatures, increase the pellet strength. A loss in the weight of the pellets has been cited as evidence of these reactions. This loss occurs through the decomposition of sodium carbonate as it reacts with silica and lime to form silicates and carbon dioxide gas that is lost to ambient. A batch containing burned lime and soda ash will lose between 9.5 and 12.5 percent of its weight depending upon the amount of hydration and carbonation that occur during agglomeration. The major weight loss is from the soda ash. Note that soda ash will not decompose unless it reacts with silica and/or lime to form a new compound. Heated by itself soda ash simply melts without any loss of CO_2.

Grinding of raw materials can be especially important in promoting the high-temperature bond (37). Diffusion-controlled, solid-state reactions are very dependent upon the specific surface available for reaction. Of great importance is the amount of fine silica in the glass batch (30). Studies in the literature indicate that silica reactions can be shifted to lower temperatures by the use of finer materials. A 1965 study by Wilburn (41) demonstrated that reactions can be lowered a minimum of 70°C by decreasing batch particle size to 300 mesh. Kroger (25) and his co-workers have also found that fine grinding increases reaction rate.

Several studies have shown the advantages of adding batch as a pretreated or prereacted material. Giegerich (14) found that the melting time was reduced by 57 percent when agglomerated batch was preheated to 750°C. Zaliznyak (43) found that melting time was decreased 60 percent when the glass batch had been preheated to 750°C. He also found the melting time was related to the amount of unreacted sodium sulfate. Raf (36) reported that agglomerates made from fine-grained materials melted and fined faster than those made from coarse-grained glass batch materials.

The patent literature is extensive in the area of shaft furnaces and other kinds of equipment used for preheating glass batch and other materials. Kunzel (P-1), in 1928, describes a process of making glass in a shaft furnace. Nelson (P-4), Howard (P-5,P-7,P-8), and Henry (P-10) all have patents which relate to the preheating and melting of glass batch in shaft furnaces. Many recent patents also include systems for preheating glass batch which include, as a part of the system, a shaft furnace.

Melting of Glass Batch

Glass batch, which is composed primarily of sodium carbonate, silica, and limestone or burned lime undergoes a number of thermal reactions, as it is brought up to high temperatures, including the formation of intermediate liquid phases. These liquids can be referred to as intermediate because when the glass batch is held at lower temperatures, these liquids will form, react with silica or other raw materials, and re-crystallize, forming a new compound that does not melt until higher temperatures are reached. This intermediate liquid is a soda-lime rich liquid which is more fluid than the final glass. In glass melting furnaces, where cold batch is placed directly into the high temperature environment, this intermediate liquid can be observed running down the batch piles. Because of the higher temperatures and short contact time with the silica in the batch, the liquid does not re-crystallize. The result is that a silica-poor liquid can be formed, which can segregate itself from the silica-rich batch. Homogenization can entail the remixing and dilution of the silica-rich batch by the silica-poor liquid.

The fact that agglomerated batch melts faster than loose batch is well documented. Pugh (35) derived equations which predict the melting times of glass batches that are fed by screw and blanket charges to a melter. The effect on melting time of preheating the batch and/or substituting caustic soda for sodium carbonate and calcium hydroxide or calcium oxide for calcium carbonate is predicted by these equations. Heat transfer is low until a liquid phase appears. Consequently, preheating glass batch to the liquid's temperature should promote faster melting.

Also, when an agglomerate melts, the intermediate liquids tend to consolidate with the agglomerate rather than separate or segregate from it. Pugh concludes that preheating of batch to a temperature below that at which molten phases exist could increase melting rates by as much as 40 percent. He also concludes that substitution of hydroxides or oxides for carbonates could increase melting rates by 20 to 30 percent. Whether a comparable increase in the rate of refining or bubble removal would also be found has not been examined. Formation of metasilicate compounds in a preheater can be viewed as desirable. Not only do these compounds increase bonding within the pellet, but their formation should improve the melting operation. Silicate compounds are melted instead of the lower-melting constituents such as soda ash. Since reactions between batch materials to form silicates are endothermic, and their reaction rates are fairly slow, segregation occurs in the melter before reactions can proceed to completion. If the silica grains are surrounded by metasilicate layers, then less segregation, and faster melting and solution of silica can be expected. In addition, if CO_2 is evolved while the agglomerated batch is still porous, it can easily escape from the batch, and the refining rate should improve.

The melting operation is primarily a function of the particle size of the silica which is being taken into solution, accounting for 90 percent of the time required for a melt to become batch-free. Costa (5), investigating the melting behavior of pelletized glass batch, has found that batch-free time can decrease by 40 percent using an optimum pellet size of 10 to 12.5 mm. Daniels (7) has found that the melting time of pelletized glass batch as compared to normal loose batch for flint composition is decreased by 24 percent. Another important aspect deals with the homogeneity of the melt or the elimination of segregation during melting. Very little is known about the magnitude of segregation which does occur, but agglomerated glass batch is expected to tend to minimize it.

LITERATURE ABSTRACT LIST

(1) Bhrany, U. N., R. T. Johnson, T. L. Myron, and E.A. Pelczarski. 1962. Dynamics of pelletization. Pages 229-249 in W.A. Knepper, ed. Agglomeration. Interscience Publishers, New York.

The formation of green iron-ore pellets for blast furnace feed is studied as a function of moisture addition and pelletizer operation. Residence time was found to be the single most important factor influencing pellet quality, with moisture content also of importance. It was also shown that pellets are formed by collision or cohesion of particles encapsulated by a thin film of water. Capillary forces were also found to be important in pellet formation. Finally, each ore was found to have a critical moisture-retaining capacity.

(2) Boffe M. and G. Letocart 1962. The influence of the size of raw materials on the rate of melting of glass. Glass Technol. 3:117-123.

The particle size distributions of different raw materials are studied for their influence on batch-free time in the glass melt.

Batch-free time was found to be dependent on the grain size of the sand, but not directly related to its specific surface area when a wide particle size distribution is present. The size of the limestone or dolomite grains was not important unless they were significantly larger than the sand. Compaction or moistening of the batch had no effect on the batch-free time.

(3) Brooks, K. L. 1971. Report on the preheating of glass pellets. Columbia Gas System Service Corp. report, October, 1971.

The heat-transfer coefficients of pellets, both single and in fixed or moving beds are experimentally determined as well as the heat capacities of the pellets. There parameters are then used to design a plant-scale pelletizing/preheating operation.

(4) Browning, J. E. 1967. Agglomeration: Growing larger in applications and technology. Chemical Engineering. :147-170.

Various methods of solid-agglomeration techniques are examined and compared. An outline guide to processes and equipment and an article on selecting binders and lubricants for agglomeration processes is also included. The heat reaction of agglomerates is briefly discussed.

(5) Costa, V. P. 1977. Investigation of the melting behavior of pelletized glass batch. Glastechnische Berichte. 50(1):10-18.

The melting behavior of different size pellets (5-15 mm) is studied in a model tank furnace and compared to loose batch for a normal commercial glass composition. Batch-free time was decreased by 40% using an optimum pellet size of 10-12.5 mm. The pellet melts were found to contain more seeds, which could influence the fining time required for the melt.

(6) Bauer, W. C. 1977. Pilot plant test program for glass batch briquetting, prereacting, and melting. Colorado School of Mines Research Institute report, September 23, 1977.

A pilot-plant facility operated by Ball Brothers Corporation at Muncie, Indiana was operated in early 1977 for testing of briquetted glass batch. Loose batch, green briquettes, and calcined briquettes (1500°F) were compared for their influence on glass homogeneity, melting rate, and pollution abatement. Glass pull from loose batch was 125 lb/hr; with briquette feed this figure was as high as 250 lb/hr, although seed count increased. Green briquettes decreased fuel requirements by 25% and calcined briquettes by 42% over loose batch. Batch was wetted at 4-7 percent moisture for briquetting. Briquetter roll wear was measured and determined to be insignificant. A Harrop Osciplate calciner was used to preheat briquettes. Briquettes decreased stack emissions significantly.

(7) Daniels, M. 1973. Melting characteristics of glass-batch materials. Glastechnische Berichte. 46(3):40-46.

Time/temperature relationships were measured for melting normal loose batch and pelletized batch of a flint glass composition. The melting time was decreased by 24% using pelletized batch. The pellets were found to absorb a higher ratio of radiant energy from the superstructure in melting and exhibited better heat adsorption from the glass bath than loose batch. The greater gap volume in pelletized batch also was found to allow more rapid escape of gases from the melt.

(8) Downing, J. H. 1967. Heat transfer in a granular bed at high temperature. Electric Furnace Proceedings, Electric Furnace Conference Papers. Vol. 26, The Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers. 26:81-83.

The mechanisms of radiation, gas conduction and convection, and solid conduction are related to heat transfer in beds of solids. Experimental studies of heat flow into granular beds of solids under vacuum and elevated temperatures are carried out to determine various time/temperature relationships. The transfer of heat in the solids beds at temperatures up to 100°C was explained as a combination of radiation and solid conduction.

(9) Eloy, P., M. Jaupain, and E. Plumat 1958. Influence of batch preparation on the rate of melting. Union Scientifique Continentale Du Verre, Symposium on the Melting of Glass, Paper I4, pp. 213-238.

Hydration of glass batch, granulometric composition of the batch, compression of batch into briquettes, and combinations of the above were studied for their effect on the melting and homogenization of glass. An optimum amount of water (6-8 percent) was found to increase the melting rate by 35%. An optimum particle size of 300 μ increased the melting rate, whereas very fine ground materials inhibited melting by scum formation. An optimum compression of 10 kg/cm^2 decreased melting time by 25%. Wetting and briquetting together decreased melting time by 60%. There was no appreciable interaction between wetting and a decrease in grain size and briquetting.

(10) Engelleitner, W. H. 1972. Pellets cut costs, improve quality. The Glass Industry.

A history of batch agglomeration and numerous references to work in this field are given.

(11) Fejer, M. E., D. H. Larson, and J. D. Nesbitt 1972. Submerged combusion melting of briquetted glass batch. Consolidated Natural Gas Service Co., Inc., and Southern California Gas Co. report on Project 8569, September, 1972.

Tests were made at a Ferro Corp. plant using submerged combustion in a glass melter to evaluate briquettes versus cullet and a loose batch in terms of melting efficiency, fuel economy, and emissions control. Briquettes were found to melt faster and more economically than loose batch while reducing stack emissions.

(11a) Fejer, M. E. 1971. A technical and economic analysis of pollution control and production boosting by glass batch pretreatment.

Institute of Gas Technology report on Project 3569, May 15, 1971.

Cost comparisons were made for a production range of 30-1000 TPD for pellets and briquettes, with the result being that costs were similar. Briquetting trials were conducted and melting rates of loose batch and briquettes were compared, with briquettes melting 2-3 times faster than loose batch. Sulfate removal tests were conducted in packed beds of briquettes, where, at 585°F 35% of the particulates were removed; while at 1250°F, only 8% of the particulates were removed.

(12) Glass Container Industry Research Corporation. 1975.
Pelletizing Glass Batch.
January, 1975.

GCIRC investigated various methods of glass-batch agglomeration. The disc pelletizing method was chosen as most suitable, and furnace trials were run at the Castle Hanson Corporation plant in Rochester, New York. Burned dolomite was used as a binder and the pellets were dried before melting. There was no difficulty storing pellets. Fuel consumption was lowered by 6% with pellets and dust carryover was greatly reduced. The pellets, made without premixing the raw materials, showed good uniformity.

(13) Glass Container Industry Research Corporation. 1969.
Pelletizing Glass Batch, Second Plant Test.
Report D-30021, January, 1969.

Pellet tests were conducted in a Maryland Glass Corp. 35 ton/day melter. The pellets were made by extrusion, with burned lime used as a binder. Many problems were experienced with the extrusion method. Pellets caused an increase in glass density and an increase in production with less dust carryover. However, the melter temperature was increased by 50°F to eliminate stones, thus no energy savings were achieved with the pelletized batch.

(14) Giegerich, W. 1951. Batch processing before fusion. Glastechnische Berichte. 24:293-301.

Briquettes and pellets were evaluated for their influence on melting time. Various binders such as water, clay, and sodium silicate were examined. The agglomerated batch was presintered in a calciner or rotary kiln where some sulfate was captured. Batch melting time decreased with increasing calciner temperature.

(15) Hanson, J. 1963. Batch wetting. Ceramic Soc. 32:78-79.

The addition of water or caustic soda to the glass batch radically improved the operation by eliminating cords and carryover. The addition of caustic soda also resulted in fuel savings.

(16) Herring, A. P. 1969. Homogeneity of pelletized batch from Knox Test. Communication with W. H. Manring, Colorado School of Mines Research Institute, March 7, 1969.

Pelletized batch samples from a GCC test in Knox, Pennsylvania on February 18, 1969 were analyzed for dolomite, soda ash, and acid insolubles. The outer 1/4 of the pellets was compared to the inner 3/4 for chemical homogeneity. Uniformity between pellets was good, but evidence of sodium enrichment on the outer surface and depletion in the core indicated migration of sodium to the surace of the pellets.

(17) Hill, R. F. and W. R. Ott. 1976. Optimization of prereacted lead glass batch. Amer. Ceramic Soc. Bull. 55(2):211-213.

Prereaction of litharge, silica, and other compounds, is studied as a means of reducing dusting, segregation, and lead volatilization during lead glass production. Optimum partical size distributions of litharge and silica are determined based on melting studies in which a significant reduction of lead volatilization occurred. This study was based on previous modelling experience and knowledge of reactions in the silica - tribasic lead silicate - potassium and sodium carbonate systems.

(18) Ironman, R. 1962. The automatic vertical cement kiln - 50 years later. Rock Products 8:81-84.

The benefits of the vertical kiln for cement production are discussed. The feed material is processed in a disc pelletizer. The discharge gate is either mechanically or hydraulically operated; however, for larger outputs the hydraulic system is preferred.

(19) Kapur, P. C. and D. W. Fuerstenau. 1964. Kinetics of green pelletization. Trans. Soc. Mining Engineers. :348-355.

The kinetics of green pellet growth in a lab balling drum were studied. Empirical equations were derived to describe pellet nucleation and growth in the drum as a function of specific surface of the particles in the pellets. Rate constants for pelletizing were determined to be highly dependent on the added moisture. Different types of particle coalescense are discussed.

(20) Karlsson, K. and L. Spring. 1970. Briquetting of glass batch. Glasteknisk Tidskrift. 25(4):

Optimum operating variables for glass batch briquetting were determined including dimensions, particle size feed, strength, storage, and melting characteristics. A 25% reduction in melting time is cited. Fixed plus variable costs of briquetting cited as nearly $20 per ton.

(23) Kayatz, K. 1964. The problem of uniformity in the operation of nodulizing pans. Zement-Kalk-Gips. 17(5):183-187.

The operation of a pelletizing disc is studied with particular attention to the raw materials and their particle size distributions, water sprays and locations, and disc operating parameters. The pellets were heated in a vertical kiln with initially poor results due to "popping" of pellets in the kiln. With raw material and operational changes the problem was corrected. The "popping" occurs when water vapor escapes from the pellets violently. The surface tension of pelletizing liquids are measured. Pellet strength versus porosity is also examined. Pellets with 30% porosity burst upon heating if they have a hard outer shell.

(24) Knapp, O. 1969. Briquetting and granulating glass mixtures. Glas-Email-Technik. 5:166-169.

A history of agglomeration in the glass industry is discussed with conclusions derived from previous experiments.

One study used slaked lime to strengthen briquettes. In another study, Ford Motor Co. experimented with waterglass, starch flour, and portland cement before settling on waterglass as a binder in briquettes. Flourides were used as a binder in briquettes in a Hungarian study.

Disc granulation is discussed with various advantages and drawbacks listed. The use of drying to strengthen pellets and preheating for the efficient use of waste gases is also discussed.

(25) Kroger, C. and F. Marwan. 1956. Reaction rates of glass batch melting. VI. Effects of additions on the reaction rate of soda-limestone-quartz batch. Glastechnische Berichte. 29:275-289.

The effects of additions to a batch comprised of 1 mole Na_2CO_3, 1 mole $CaCo_3$, and 6 moles SiO_2 (as quartz) on rates of reaction and their temperature coefficients were studied. The addition of cullet produced no effect, while dolomite replacing limestone and K_2CO_3 or Li_2CO_3 replacing soda ash caused changes in reaction rates. Li_2CO_3 accelerated reactions more intensly than K_2CO_3, while B_2O_3, H_3BO_3 and $Na_2B_4O_7\ 10H_2O$ also accelerated the reaction rate, though not as intensely as K_2CO_3 X H_2O. Moist batches increased melting rates by 5-10 percent. The reaction rate as a function of grain size of the reactants has a pronounced optimum for a distinct grain size distribution. Fine granular reagents may cause trouble in early sintering.

(26) Kroger, C. 1952. Chemical reactions in the glass batch. Glastechnische Berichte. 25:307-324.

The application of phase equilibrium diagrams to glass melting is discussed. To study the reactions in the fundamental Na_2O-SiO_2-CO_2 system, the presence of early "polyeutectic" melt phases was determined by continuous measurement of the electrical resistance.

The results are given in empirical formulas. Resistance versus temperature curves show differences in fusion processes between mixtures in the solid state and mixtures containing melt phases. It was found that briquetting may considerably decrease the reaction rate by inhibiting the free escape of CO_2 from the batch.

(27) Kroger, C. and G. Ziegler. 1953. Reaction rates of glass batch melting. II. Reaction of Na_2O 2 SiO_2 With Na_2CO_3 and of Quartz With Limestone. Glastechnische Berichte. 26:346-353.

In the temperature range of solid-state reactions, the rate of reaction of Na_2O 2 SiO_2 with Na_2CO_3 is smaller than that of quartz with Na_2CO_3. However, above 840°C the reaction of the disilicate is considerably accelerated when a eutectic melt phase is formed; above 865°C the rate of this reaction is nearly equal to that of quartz and Na_2CO_3 at 900°C. A conclusion is made that reactions are determined more by physical factors than chemical factors alone. Activation energies for reactions with eutectic phases are related to physical factors such as diffusion, surface tension, wetting, viscosity, and others. It is also concluded that the resistance against the reaction built up in the contact boundaries of the solid phases breaks down when eutectic melts are formed.

(28) Loffler, J. 1951. Presintering of glass batch raw materials. Glastechnische Berichte. 24:287-292.

Reactions in a preheated (presintered) glass batch are determined. A high oxygen potential was noticed in the reacted products, where the Fe was in the ferric state. There was a maximum of 70% quartz reaction in the batch up to 900°C.

(29) Manring, W. H. and W. C. Bauer. 1973. The batch preparation process - past, present, and future. Amer. Ceramic Soc. Bull. 52(83):617-620.

The advantage of wet batching with water or caustic soda is discussed. Melting segregation and particle size segregation have been found to cause melt defects as well as wide differences in the particle size ratios of the batch raw materials. Compacted batch is proposed as a method to obtain a decrease in stack emissions and more efficient melting of glass. Briquetting studies showed that a 100°C drop in furnace temperatures is possible without sacrificing quality

(30) Matveev, M. A. and B. K. Demidovich. 1967. Granulation of a glass charge". Steklo I Keramika. 24(10):20-23.

Various factors are studied for their influence on granulation and an optimum specific surface for sand is determined. It is concluded that the strength of pellets increases with the proportion of finer sand.

(31) Midland Ross Corp., Surface Combustion Division. 1969. Development of a process for glass batch pelletizing. Surface Combustion Division of Midland Ross Corp., report, June 10.

Several different glass batches were obtained from glass companies, ground to a finer particle size distribution, and then pelletized. Melting rates of the pellets were compared to the loose batch. It was determined that pellets dried at 460°F in a shaft furnace had strengths of 200-300 psi. Fuel input decreased by 6°F with pellets. It was found that 50 mesh is the maximum particle size for the batch with 45% less than 200 mesh producing satisfactory results.

The results also indicated air and water temperature affects pellet strength as they are made. Pellets were crushed under weight at 1300°F. Abrasion and tumbling indices of the pellets were also measured.

(32) Nisman, M. S., TS. M. Gekhtman, L. I. Okhrimenko, and N. V. Shkumat. 1975. Method of obtaining granulated batch for container glass.

Steklo I. Keramika, 3:14-21.

A Ukranian glass container composition was pelletized while experimenting with different binders. The optimum process used sodium silicate as a binder. Optimum operating conditions were: rim height/diameter = 0.15, pan angle= 45°, 15-22 rpm, 5-10 mm diameter pellets with 12-15 percent moisture. Drying time versus moisture studies were conducted to determine pellet strengths. Pellets were melted in production with 40% cullet with favorable results. It was also found that pellets stored for periods up to one year exhibited no decrease in strength.

(33) Pietsch, W. B. 1970. Improving powders by agglomeration. Chem. Engineering Prog. 66(1):31-34.

The various methods of powder agglomeration are discussed along with the binding mechanisms involved. Emphasis is toward briquetting, with a table provided that shows the pressure and power required to briquette various types of materials.

(34) Powell, A. S. 1973. Review of glass melting process improvement development projects. Consolidated Natural Gas Service Co., Inc., report, January.

Leone Industries and Glass Containers, Inc. batches were briquetted successfully at K. R. Komarek after some grinding and 13% water addition. Briquettes were melted at Ferro and compared to loose batch in terms of melting and pollution control. Briquettes were found to be economically feasible. Packed-bed experiments were conducted to obtain curves for pollutant capture.

(35) Pugh, A. C. P. 1968. A method of calculating the melting ratio of glass batch, and its use to predict effects of changes in the batch. Glastek. Tidskrift. 23(4):95-104.

Equations which predict the melting times of glass batches fed by screw feeder or blanker chargers to a tank furnace are given. The equations are used to predict the effect of preheating batches on melting, and of substituting NaOH for Na_2CO_3, and $Ca(OH)_2$ or CaO for $CaCO_3$ as batch components.

(36) Raf, S. Ya., and N. A. Milyaeva. 1948. Relation of the rate of glass melting to the method of feed, and the grain size of the batch. Steklo I. Keramika. 5(2):4-6.

Experiments were conducted with fine and coarse-grained loose and briquetted batches to give a glass composition of $SiO_2 + R_2O_3$ (73%), CaO (8%), MgO (3%), and Na_2O (16%). Briquettes were made from sand, dolomite, limestone, soda, and sulfate at 64 openings/cm^2 and at 4900 openings/cm^2 with 1, 2, 3, 4 and 6% H_2O. Compared to loose batch, the briquettes exhibited more rapid melting and fining. The time required for melting coarse-grained briquettes and fine-grained loose batch was nearly the same, although the former's fining was more rapid. Melting and fining of fine-grained briquettes were more rapid than for coarse-grained briquettes. It was also found that briquettes made under pressure of over 500 kg/cm^2 showed no sharp differences in melting and fining.

(37) Schorr, J. R. and K. L. Brooks. 1972. Drying and preheating pelletized glass batch. Columbia Gas Systems Service Corp., Research Department Report, July 20.

This report is based on experiments conducted under a secrecy agreement between Columbia Gas, O-I Midrex, Southern Cal. Gas Co., and Consolidated Natural Gas Co. Grinding, pelletizing, drying, and preheating studies of typical container glass batches were conducted to determine the feasibility of these systems in the glass industry. Optimum batch compositions, operating parameters, and pellet studies indicated that substantial energy savings could be realized using preheated glass batch.

(38) Tamura, Z. 1970. Pelletizing of glass batch. Nippon Glass Batch Co. report,

The history of pelletizing in the glass industry of Japan is discussed along with future prospects of development. It is noted that caustic soda is cheaper than soda ash in Japan and that pellet shipments from a central batch facility have increased considerably each year. Benefits in pollution control, tank rebuilds, employee dust exposure, and raw material costs are explained.

(39) Tonry, J. R. 1960. Pelletizing characteristics of raw mixes. Pit and Quarry, 8:102-106; 92:117-121, 132.

Cement pellets were tested for load-carrying capacity, abrasion resistance, and popping tendency. Larger pellets (1 in dia.) were found to have a greater popping tendency as a result of moisture loss than smaller pellets. Porosity and permeability were examined for their influence on other pellet properties. Various additives were examined for their effect on pellet properties. Thermal analyses were made to determine the reactions occurring in the pellets.

(40) Tooley, F. V. and R. L. Tiede. 1946. Influence of batch mixing time and batch grain size on homogeneity of a soda-lime-silica glass. Amer. Ceramic Soc. 7:197-199.

Density-spread determinations were made on a series of melts of a soda-lime-silica glass employing batches compounded from raw materials varying in particle size from 20 to 60 mesh to minus 200 mesh, which had been mixed by tumbling for one, ten, or thirty minutes. The two melting techniques employed were (1) melting for sixteen hours in a stationary platinum crucible at 1400°C under conditions of even temperature distribution and consequently a minimum of convection mixing and (2) melting for four hours at 1400°C in a rotating tilted crucible; this condition was intended to simulate convection mixing.

Under the experimental conditions employed, it was found that (1) batch mixing time has relatively little effect on the homogenizing rate, (2) homogenization increases rapidly with decreasing in grain size, and (3) in all cases the 4 hour melting treatment with moderate mixing gives better homogeneity than sixteen hours melting time in a stationary crucible, this effect increasing with decrease in grain size.

No significant difference in glass homogeneity resulted from three different methods of mixing, namely, tumbling, ball milling, and mixing in a muller-type mixer, although the homogenizing influence imposed probably was sufficient to mask any differences in uniformity of mixing that might have existed.

(40a)Vityugin, V. M., V. A. Trofemov, and L. G. Lotova. 1977. Thermogranulation of soda-containing glass charges without addition of binders. Steklo I. Keramika. 2:8-11.

Granulation of glass batch is performed by heating the charge initially to about 50°C (by heat of hydration of carbonates), cooling, and then granulating in a drum. Pellets are then cooled by an air fan on discharge. This treatment resulted in increased pellet strength, but less porosity and stability during storage.

(41) Wilburn, F. W., S. A. Metcalf, and R. S. Warburton. 1965. Differential thermal analysis, differential thermogravimetric analysis and high temperature microscopy of reactions between the major components of a sheet glass batch. Glass Tech. 6(4):197-14.

Reactions during melting of glass batch materials were studied with the aid of a high temperature microscope and DTA-TGA methods. Results showed that sodium carbonate begins to react at 930°F with dolomite and limestone forming sodium-calcium carbonate, and in the process setting free magnesium carbonate which later decomposes at 1165°F.

The sodium-calcium carbonate melts as a eutectic with a second (unknown) compound at 1436°F and accelerates a reaction between uncombined soda ash and silica at 1560°F. Silica dissolves into the liquid phases formed at 1560° F, and at 2000°F about 86% of the sand has been converted to the liquid phase.

(42) Yamamoto, J. and E. Komatsu. 1968. Pelletizing the glass batch. The Glass Industry. 9:491-493.

Nippon Glass Co. since 1965 has successfully pelletized glass batch and fed it to their furnaces with a greater than 35% increase in pull over loose batch feed. They use caustic soda as a binder and replacement for soda ash (50-100 percent replaced) and fine-ground sand for increased pellet strength and earlier formation of silicate compounds for easier melting. The fining practices for pellets are different than those used for loose batch, thus adjustment is needed on a case basis.

(43) Zaliznyck, D. V., et al. 1959. The affect of thermal preparation of the raw mix on glass fusion. Steklo I. Keramika. 16:21-27.

Pretreated or fused glass batch is reviewed at length. Results indicate that it adds flexibility to the glass-making phase of the furnace operation, reduces corrosion of the regenerators by aggressive gases, shortens the melting period, and conserves fuel by preheating in a furnace with 70-75 percent efficiency instead of a glass tank with 16-18 percent efficiency.

Records of actual practice verify favorable economics. Melting time is dependent on the content of unreacting Na_2SO_4 and increases 50% when there is 5 to 10.6 percent Na_2SO_4 in the thermally prepared batch. Tank output can be increased by 35 to 40 percent.

PATENT ABSTRACT LIST

(P-1) U.S. 1,676,267 7/1928 Kunzel

Process of making glass in a shaft furnace:

A process of making glass in a shaft furnace where the flame produced by burners is drawn through the batch materials in the shaft by suction is described. The furnace can be heated by solid fuels.

(P-2) U.S. 2,114,545 4/1938 Slayter, assignor to Owens-Illinois Glass Company

Sintering glass batch:

Glass batch and cullet is preheated in a sintering chamber while moving on a conveyor belt. The cullet is first discharged onto the conveyor, batch is spread over it, and then the mass is sintered and fed to the glass furnace.

(P-3) U.S. 2,366,473 1/1945 Bair, assignor to Norbert S. Garbisch

Glass batch:

Pelletizing of glass batch in a tumbling mill is proposed to minimize dusting and homogeneity problems in glass tanks. Many experiments were undertaken to determine the optimum binders and particle size distributions for durable pellets. Briquettes are also mentioned as being desirable.

(P-4) U.S. 2,450,013 9/1948 Nelson

Apparatus for producing rock wool:

Raw materials are preheated in a cupola to produce slag for rock wool production.

(P-5) U.S. 2,564,783 8/1951 Howard

Glass melting furnace and method:

Briquetted glass batch is fed into a shaft preheater to promote more rapid melting, longer refractory life, better glass uniformity, and the reduction of seeds and striate. Raw materials with higher melting points are fed separately from the other raw materials and eventually melt together in a downward stream in the shaft furnace.

(P-6) U.S. 2,578,110 12/1951 Tooley, assignor to Owens Corning Fiberglas Corporation

Production of glass:

Glass uniformity is enhanced by the use of preheated, briquetted batch. Fine particle sizes are employed (325 mesh) and briquettes are formed in presses or by extrusion. They are preheated to 800°F - 1750°F for 30 to 180 minutes and fed into the melting tank.

(P-7) U.S. 2,597,585 Howard

Glass melting method and apparatus:

Glass batch is briquetted and fed into a preheating furnace along with lumps of refractory materials to maintain a filter bed character. Advantages of greating melting capacity and fuel economy are claimed.

(P-8) U.S. 2,597,640 5/1952 Howard

Glass melting method:

A method of preheating glass batch where briquettes are preheated, sintered and melted to produce a more uniform glass is described. The preheating is accomplished in a vertical furnace containing refractory lumps which aid in refining the glass.

(P-9) U.S. 2,665,996 1/1954 Kalousek

Hydrous calcium silicates and method of preparation:

Reactions in the $CaO-SiO_2-H_2O$ system are examined up to 750°C and an intergrated porous hydrous calcium silicate product is described along with optimium methods for its manufacture.

(P-10) U.S. 2,718,096 9/1955 Henry and Brichard, assignors to Union des Verreries Mecaniques Belges.

Apparatus for Melting Glass and the Like:

Loose glass batch is preheated in a shaft prior to melting under high pressure, temperature, and air speed. The shaft bottom is the melting part of the furnace and a refiner is attached.

(P-11) U.S. 3,001,881 9/1961 Slayter, assignor to Owens Corning Fiberglas Corporation

Prereacted glass batch:

150 mesh silica is mixed with the other raw materials then autoclaved under at least 100 psi at 325°F. Autoclaving is continued until at least a 40% reaction of the silica occurs, when most of the remaining silica is <5μ. The batch is then ready for rapid melting in a small furnace.

(P-12) U.S. 3,082,102 3/1963 Cole et at., assignor to Pilkington Brothers

Processes of manufacturing glass:

Pelletized glass batch is prereacted in a rotary kiln at a maximum temperature of 900°C on a continuous basis for lower melting temperatures, reduction of sulfate emissions, and increased production.

(P-13) U.S. 3,172,648 3/1965 Brichard, assignor to Union des Verreries Mecaniques Belges Society Anononyme

Melting hearth:

A melting hearth design which uses a countercurrent waste heat gas flow to preheat pulverized materials before charging them into a molten bath is described.

(P-14) U.S. 3,185,554 5/1965 Sweo, et al., assignors to Ferro Corporation

Method for preheating porcelain enamel batch:

Porcelain enamel batch is preheated to drive off volatiles before introduction to the charging zone in a continuous process.

(P-15) U.S. 3,190,625 6/1965 Brichet, et al., assignors to Glaverbel

Preheating process and apparatus:

A preheating process and apparatus for vitrifiable compositions is described in which raw materials are preheated in a shaft furnace above the melting compartment. Waste gases are used for the preheating.

(P-16) U.S. 3,427,367 2/1969 Krehl, assignor to Societe Generle Des Produits Refractories

Method of prefiring refractory materials:

Refractory materials are prefired in a shaft kiln with a countercurrent hot air flow. Particle size, porosity, and air flow are mentioned.

(P-17) U.S. 3,459,411 8/1969 Jacobs, assignor to Glaverbel S. A.

Furnace arrangement and method:

A furnace arrangement and method are proposed wherein loose batch raw materials are preheated and flow by gravity into the glass tank.

(P-18) U.S. 3,589,885 1/1970 Pugh

Soda-lime material for use in glass-manufacture:

A prereacted soda-lime material is described as a source of Na_2O and CaO for use in soda-lime glasses. The material is a free-flowing mixture of sodium hydroxide and calcium hydroxide containing at least 5 percent water, and is made by slaking quicklime with a concentrated caustic soda solution. The material is claimed to melt more rapidly in a glass furnace than conventional raw materials, resulting in increased melting rates and lower fuel consumption.

(P-19) U.S. 3,526,492 9/1970 Motsch

Glass premelter:

A glass premelter is described where premoistened raw materials are preheated by depositing them on an island below the crown and allowing them to flow into the melting chamber. Countercurrent air flow is preferred so that regenerators would not be needed to preheat the incoming combustion air.

(P-20) U.S. 3,542,534 11/1970 Yamomoto

Process for pelletizing glassmaking materials:

Pellets are made from fine ground glass batch raw materials using caustic soda as a binder to increase production. Pellets are dried and/or preheated and could be mixed with cullet before charging to the furnace.

(P-21) U.S. 3,545,988 12/1970 Slade, assignor to Owens-Illinois

Glass manufacturing method:

Free-flowing agglomerates of sand and light soda ash are formed at elevated temperatures in a rotary kiln. When melted in a furnace the agglomerates reduce dusting and prolong refractory life.

(P-22) U.S. 3,555,133 1/1971 Gentax, assignor to Battelle Memorial Institute

Method for producing pellets:

A description is given of a method of producing pellets from finely divided materials by rolling nuclei or seeds of inorganic binder and water on a tumbling bed of the material. The particles agglomerate in layers and are discharged when reaching the desired pellet size.

(P-23) U.S. 3,573,887 4/1971 Mod and Caldwell, assignors to Dow Chemical Company

Method of making glass:

Glass is made from reacted and shaped batch materials. Alkali metal hydroxide is a batch constituent; the batch is formed into an elongated shape and preheated before charging to the furnace.

(P-24) U.S. 3,601,377 8/1971 Jope, assignor to Catagas Ltd.

Shaft furnaces:

A shaft furnace design for mineral calcining is described which employs a countercurrent heat flow through parallel shafts.

(P-25) U.S. 3,607,190 9/1971 Penberthy

Method and apparatus for preheating glass batch:

Loose glass batch flows from a hopper where it is preheated to 1200°-1500°F in a rotary kiln by a gas burner or by using waste gases. Refining agents and cullet could be added separately.

(P-26) U.S. 3,637,365 1/1972 Dulton, assignor to Pilkington Brothers, Ltd.

Preheating glass batch:

A process is described in which glass batch is preheated by allowing loose batch to flow past an electrode which melts the batch core and insulates the electrode. The preheated batch is then conveyed to the melting furnaces.

(P-27) U.S. 3,726,697 4/1973 Mod and Caldwell, assignors to Dow Chemical

Glass manufacture from prereacted batch and composition:

A batch containing 4-20 percent alkali metal oxides is prepared using at least 50% of the alkali as caustic. The batch is substantially reacted prior to melting. Reduced melting and fining times are claimed.

(P-28) U.S. 3,728,094 4/1973 Bowman

Process of making glass:

A glass making process is described in which the glass batch is pelletized or briquetted and waste furnace gases are passed by the agglomerated in a packed bed for capture of the pollutants in gases. Pollutants not removed in the packed bed are removed in a subsequent scrubbing step. The material captured in the scrubbing apparatus is used as feed for the agglomerating step and mixed with the other raw materials.

(P-29) U.S. 3,730,503 5/1973 Holley, assignor to Internation Mineral and Chemical Corp.

Apparatus and method of agglomerating and hardening metal oxide pellets:

Raw materials are agglomerated using a binder and the moist, green pellets are introduced to a pressurized preheating device which operates on a batch type basis.

(P-30) U.S. 3,760,051 9/1973 Eirich

Method of forming granules:

A method of forming granules from glass batch by the addition of caustic soda and limestone is described. Heat is also applied to facilitate pellet formation.

(P-31) U.S. 3,765,854 10/1973 Kozlowski, assignor to Ball Corporation

Method and apparatus for constant moisture in glass batch:

A method and apparatus are claimed for maintaining constant moisture in a wetted glass batch where the glass level of the furnace is monitored and the water is fed into the screw in proportion to the amount of batch fed to the furnace.

(P-32) U.S. 3,767,751 10/1973 Simmingskold and Carbol, assignors to Glasforskningsinstitutet

Process for making pelletized glass batches:

Glass batch is pelletized by subjecting the raw materials to a stream in the pelletizer to facilitate granule formation. The steam temperature is between 100-600°C. Method developed using lead glass batch.

(P-33) U.S. 3,772,946 11/1973 Hofer and Schmid

Method for carrying out endothermic processes in a shaft furnace:

Endothermic processes are carried out in a shaft furnace design comprised of two spaced shafts which contain preheating combustion, and cooling zones. The shafts are joined together at the lower end of the combustion zone. Air flow is countercurrent to the material flow.

(P-34) U.S. 3,782,906 1/1974 Pierce, assignor to Philadelphia Quartz Company

Process for preparation of glass particles:

A process for the preparation of agglomerated hydrated alkali metal silicate glass particles is described where the free flowing glass particles are fed into a fluidized bed using steam to expand the bed, thus hydrating and agglomerating the glass particles.

(P-35) U.S. 3,880,639 4/1975 Bodner, et al., assignors to Owens-Illinois, Inc.

Bodner, John J., Grubb, Everett F., McCormack, Kenneth J., and Moore, Ronald H.

Sulfur recovery from glass melting and refining:

Sulfur is recovered from glass melting and refining by passing the waste gases through a packed bed of agglomerated raw materials. The sulfur input and output will always be balanced by proper additions to the batch.

(P-36) U.S. 3,788,832 1/1974 Nesbit and Fejer, assignors to Institute of Gas Technology

Process for pretreating and melting glassmaking materials:

Batch raw materials are briquetted, preheated with waste gases and melted in a furnace using submerged combustion burners.

(P-37) U.S. 3,789,628 2/1974 Mahoney, assignor to Ball Corporation

Method for controlling furnace emissions:

Furnace emissions are controlled by spraying an aqueous sodium silicate solution into the exhaust stack and then collecting the precipitate and recycling it back into the furnace.

(P-38) U.S. 3,907,956 9/1975 Meinier, assignor to Saint-Gobain Inc.

Method of agglomerating glass batch materials:

Glass batch materials are agglomerated in a fluidized bed where preheated sand granules are reacted with a spray of aqueous metal hydroxide solution, raked, and agitated.

(P-39) U.S. 3,914,364 10/1975 Engelleitner and Floyd, assignors to Dravo Corporation

Method of pelletizing glass batch:

Glass batch materials are pelletized using caustic soda as a binder with coarse sand and fine ground limestone. The sand is specified as 50 x 200 mesh and the limestone is 70% minus 325 mesh. Most of the Na_2O is supplied by caustic soda added to the batch before or during pelletizing.

(P-40) U.S. 3,944,713 3/1976 Plumat and Marresse, assignors to Glaverbel-Mecaniver

Method and apparatus for preheating vetrifiable batch:

Loose vetrifiable batch is preheated by passing hot waste gases by a support in a preheating chamber.

(P-41) U.S. 3,953,190 4/1976 Lange, assignor to Pullman, Incorporated

Pellet preheating and volatile recycling structure:

A pellet preheating and volatile recycling structure for glass making furnaces is described where pellets are preheated in a shaft furnace using waste gases which are scrubbed free of particulates.

(P-42) U.S. 3,969,100 7/1976 Kuna and Sowman, assignors to Ford Motor Company

Method of pelletizing glass batch materials:

Glass batch is pelletized with the addition of caustic soda and water. Different zones of pellet growth are discerable and controllable in the pelletizer.

(P-43) U.S. 4,017,264 4/1977 Meian, assignor to Allis Chalmers

Pan agglomeration with mechanical pellet classification:

Pellets are formed in a disc pelletizer and mechanically stripped from the disc to effect an even particle size distribution for improved strength, abrasion resistance, and size conformity. Pellets could be heated in a moving bed (grate) to dry and increase their strength.

(P-44) U.S. 4,023,976 5/1977 Bauer and Howard, assignors to FMC

Manufacture of glass:

A continous glass manufacturing process wherein briquettes are made using water and caustic soda as binders is described. The mixed batch is aged for at least ten minutes, fed as particulates to the briquetting machine and preheated to a temperature between 750-900°C for silicate formation during prereaction. The briquettes are charged to a furnace with lower operating temperatures in order to reduce sodium volatilization.

(P-45) U.S. 4,026,691 5/1977 Lovett and Dickerson, Jr., assignors to Dow Chemical Corp.

Pelletized glass batch:

A method of pelletizing glass batch for soda-lime glass manufacturers is described wherein caustic soda and some limestone in the batch are slurried and added to the other materials at the pelletizer. The pellets are dried to attain complete reaction of the caustic soda.

(P-46) U.S. 4,074,989 Brzozowski and Cooper, assignors to PPG Industries, Inc.

Method of preparing anhydrous boric acid - containing glass batch:

A process is described for preparing anhydrous boric acid (ABA)-containing glass batch compositions suitable for the preparation of glass fibers. The batch, prior to its introduction into the furnace, is pelletized by adding water in sufficient quantities to maintain an adequate balling action, and thus provide pellets in a form such that preheating by direct contact with flue gases does not cause deterioration of the pellets.

(P-47) U.S. 4,074,990 Brzozowski and Cooper, assignors to PPG Industries, Inc.

Method of preparing colemanite - containing glass batch:

A process is described for preparing colemanite-containing glass batch compositions suitable for the preparation of glass fibers. The batch, prior to its introduction into the furnace, is pelletized by adding water in sufficient quantities to maintain an adequate balling action, and thus provide pellets in a form such that preheating by direct contact with flue gases does not cause deterioration of the pellets.

(P-48) U.S. 4,074,991 Brzozowski and Cooper, assignors to PPG Industries, Inc.

Method of preparing boric-acid containing glass batch:

A process is described for preparing boric acid-containing glass batch compositions suitable for the preparation of glass fibers. The batch, prior to its introduction into the furnace, is pelletized by adding water in sufficient quantities to maintain an adequate balling action, and thus provide pellets in a form that preheating by direct contact with flue gases does not cause deterioration of the pellets.

(P-49) B.P. 1,172,318 Compagnie de Saint-Gobain

Pre-treated glass batch material and method of preparing same:

This method describes the use of melt activators to cause lower temperature reactions in preheated glass batch. The activators are alkali metal halides which cause the decomposition of sodium carbonate within the range of 600°-787°C to form a eutectic composition with the sand. This sand reacts with calcium carbonate to coat the same grains and decrease the melting time of the batch.

APPENDIX B
TECHNICAL RESULTS

TABLE B-1. SODA-LIME BATCH RAW MATERIAL ANALYSIS

Raw material vendor location	Oxide weight percent						
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3
Berkeley No. 1 dry sand Pennsylvania Glass Sand (PGS) Berkeley Springs, W. Va.	99.65	0.11					0.03
Berkeley Fine Dry Special PGS Berkeley Springs, W. Va.	99.6	0.1					0.03
Berkeley -40 mesh PGS (Lab Prepared) Berkeley Springs, W. Va.	99.65	0.11					0.03
Berkeley -50 mesh PGS (Lab Prepared) Berkeley Springs, W. Va.	99.65	0.11					0.03
200 mesh supersil PGS Berkeley Springs, W. Va.	99.67	0.09	0.02				0.025
Oklahoma No. 1 dry sand PGS Mill Creek, Oklahoma	99.8	0.09	0.01				0.02
Pulverized burned limestone Warner Company Bellefonte, Pennsylvania	1.9	1.0	93.52	1.14			

(continued)

TABLE B-1. (Continued)

Raw material vendor location	Oxide weight percent						
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3
Chemical hydrated lime H. J. Grove Lime Co. Frederick, Maryland	0.04	0.50	73.0	0.74			0.08
330 nepheline syenite Nephton, Ontario	59.8	23.6	0.6	0.1	10.2	5.0	0.07
340 nepheline syenite Nephton, Ontario	59.8	23.6	0.6	0.1	10.2	5.0	0.07
A200 nepheline syenite Nephton, Ontario	60.5	23.3	0.6	0.1	9.8	4.6	0.09
Dense soda ash Stauffer Chemicals Green River, Wyoming							
Warner glass grade limestone Warner Company Bellefonte, Pennsylvania	1.9	0.2	53.98	0.51			0.14
Warner - 50 mesh limestone (Lab prepared) Bellefonte, Pennsylvania	1.9	0.2	53.98	0.51			0.14
Warner pulverized limestone Warner Company Bellefonte, Pennsylvania	1.9	0.2	53.98	0.51			0.14

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TABLE B-1. (Continued)

Raw material vendor location	Oxide weight percent						
	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3
No. 40 burned dolomite The National Lime and Stone Co. Carey, Ohio	0.2	0.2	58.9	40.6			0.14
No. 100 burned dolomite Ohio Lime Woodville, Ohio	0.15	0.26	56.5	42.5			0.10
No. 26 hydrated lime National Gypsum Co. Kimballton, Virginia	1.3	0.16	73.14	1.70			0.2
No. 4 limestone National Gypsum Company York, Pennsylvania	0.9	0.32	53.63	1.48			0.05

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TABLE B-2.

Raw material vendor location	Percent retained on U.S. series screens									
	20	30	40	50	70	100	140	200	270	Pan
Berkeley No. 1 dry sand Pennsylvania Glass Sand (PGS) Berkeley Springs, W. Va.		1.7	14.8	37.0	28.5	12.7				5.2
Berkeley Fine Dry Special PGS Berkeley Springs, W. Va.				1.2	6.6	16.2	19.7	29.2	13.9	13.2
Berkeley -40 mesh PGS (Lab Prepared) Berkeley Springs, W. Va.			TR[1]	31.0	32.4	16.4	7.8	3.4		9.0
Berkeley -50 mesh PGS (Lab Prepared) Berkeley Springs, W. Va.				TR	21.0	23.8	17.0	10.4		27.0
200 mesh supersil PGS Berkeley Springs, W. Va.								TR	5	95
Oklahoma No. 1 dry sand PGS Mill Creek, Oklahoma			TR	0.4	5.5	42.6	36.8	7.3		1.4
Pulverized burned limestone Warner Company Bellefonte, Pennsylvania						0.1		8.0		91.9

[1] TR = trace

(continued)

TABLE B-2. (Continued)

Raw material vendor location	Percent retained on U.S. series screens									
	20	30	40	50	70	100	140	200	270	Pan
Chemical hydrated lime H. J. Grove Lime Co. Frederick, Maryland						0.4		36.4	44.6	18.8
330 nepheline syenite Nephton, Ontario		0.1	18.9	29.0		38.0		12.0		2.0
340 nepheline syenite Nephton, Ontario		0.4		25.6		52.6	14.0	4.5		2.5
A200 nepheline syenite Nephton, Ontario							0.05	0.3		99.7
Dense soda ash Stauffer Chemicals Green Rivery, Wyoming		2.0	15.0	38.0	27.0	14.0	3.0			
Warner glass grade limestone Warner Company Bellefonte, Pennsylvania	2.6	19.4	22.0	22.0		26.0	5.0	2.0		
Warner -50 mesh limestone (Lab Prepared) Bellefonte, Pennsylvania			TR		23.0	30.4			42.8	3.8
Warner pulverized limestone Warner Company Bellefonte, Pennsylvania							1.0	2.0	5.0	92.0

(continued)

TABLE B-2. (Continued)

Raw material vendor location	Percent retained on U.S. series screens									
	20	30	40	50	70	100	140	200	270	Pan
No. 40 burned dolomite The National Lime and Stone Co. Carey, Ohio				4.0	15.0	11.0			46	24
No. 100 burned dolomite Ohio Lime Woodville, Ohio					1.2			13.7		84.1
No. 26 hydrated lime National Gypsum Co. Kimballton, Virginia					0.1			1.0		99.0
No. 4 limestone National Gypsum Company York, Pennsylvania			0.05		3.0			81.3		15.7

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TABLE B-3. DRAVO SERIES (DS) BATCH COMPOSITIONS AND STRENGTH TEST RESULTS

					Raw materials[b]				
Name	Temp (°C)	Force[a] N	Std dev	Strength x 10^4 Pa	Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-1	100	386.4	47.6	222.0	65A	35	50G	50I	M
	200	308.3	43.7	181.5					
	700	69.4	10.9	38.0					
DS-IA	100	210.6	51.2	147.9	65A	35	50G	50I	M
	200	180.7	46.0	132.3					
	700	23.8	9.2	17.4					
DS-IB	150	183.7	33.7	134.1	65A	35	50G	50I	M
	600	22.9	3.5	16.7					
	750	49.8	25.7	37.8					
DS-2	100	336.1	71.4	193.1	65B	35	50G	50I	M
	200	240.3	68.9	138.1					
	700	61.6	39.8	34.9					
DS-2A	150	257.1	44.5	180.6	65B	35	50G	50I	M
	600	25.2	4.7	17.7					
	750	125.2	28.4	80.2					
DS-3	100	445.1	68.6	255.8	65A	35	50G	50J	M
	200	338.1	58.3	205.4					
	700	18.1	3.2	11.4					
DS-4	100	108.8	43.0	62.5	65B	35	50G	50J	M
	200	115.1	20.5	72.4					
	700	11.1	9.5	5.5					

(continued)

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TABLE B-3. (Continued)

					Raw materials[b]				
Name	Temp (°C)	Force[a] N	Std dev	Strength x 10^4 Pa	Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-5	100	174.2	61.3	100.1	75B	25	50C	50J	M
	200	110.9	21.3	55.1					
	700	11.3	3.9	6.6					
DS-6	100	133.6	45.5	76.7	65A	35	50G	50J	M
	200	92.6	24.0	54.3					
	700	-	-	-					
DS-7	100	147.3	37.2	107.5	65A	35	50G	50I	M
	200	127.8	27.1	80.4					
	700	422.5	130.1	250.0					
DS-8	100	180.8	46.9	142.7	65B	35	50G	25I	M
	200	262.7	31.8	199.3					
	700	7.5	2.0	5.9					
DS-9	100	100.3	41.8	65.4	85A	15	25G	75I	M
	200	102.0	19.3	57.8					
	700	16. 6	4.4	9.7					
DS-10	100	115.8	52.6	72.9	85B	15	25G	75I	M
	200	112.6	38.1	68.4					
	700	49.1	21.6	32.0					
DS-11	100	76.5	27.2	51.8	85A	15	25G	75J	M
	200	61.9	17.6	38.9					
	700	2.6	1.5	1.7					
DS-12	150	192.1	35.0	101.9	65C	35	50G	50I	M
	600	34.2	5.7	17.5					
	750	438.8	67.8	140.5					

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TABLE B-3. (Continued)

Name	Temp (°C)	Force[a] N	Std dev	Strength x 10^4 Pa	Raw materials[b] Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-13	150	109.7	28.9	54.5	91C	9	50G	50I	M
	600	22.4	5.2	11.9					
	700	308.8	75.2	163.8					
DS-14	150	160.8	14.7	97.7	65D	35	50G	50I	M
	600	23.2	5.1	13.1					
	750	217.3	45.9	127.4					
DS-15	150	227.9	28.2	154.2	73D	27	50G	50I	M
	600	31.3	6.8	21.9					
	750	100.6	20.3	73.4					
DS-16	150	224.4	64.9	151.9	65E	35	50G	50I	M
	600	30.8	10.0	21.6					
	750	302.5	83.5	229.5					
DS-17	150	176.7	22.5	111.2	91E	9	50G	50I	M
	600	23.7	4.7	14.4					
	750	123.4	70.4	86.7					
	New preheating cycle for remaining batches								
DS-18	200	115.2	28.9	87.4	65A	35	50G	50K	M
	650	19.8	11.2	12.9					
	705	42.2	13.4	29.6					
DS-18A	200	197.7	49.0	112.1	65A	35	50G	50K	M
	650	26.4	7.7	14.0					
	750	79.5	27.7	46.6					

(continued)

TABLE B-3. (Continued)

Name	Temp (°C)	Force[(a)] N	Std dev	Strength x 10^4 Pa	Raw materials[(b)] Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-18B	200	159.4	31.8	104.0	65A	35	50G	50K	M
	650	37.5	9.4	29.6					
	750	65.4	22.8	51.6					
DS-19	200	263.2	54.6	165.6	65A	35	50H	50K	M
	650	56.0	14.0	35.2					
	750	73.3	19.6	44.5					
DS-19A	200	192.1	43.4	108.9	65A	35	50H	50K	M
	650	37.5	10.5	22.0					
	750	62.2	15.5	39.6					
DS-19B	200	250.0	51.7	163.1	65A	35	50H	50K	M
	650	17.7	5.3	10.2					
	750	33.8	7.7	22.0					
DS-21	200	194.5	42.6	126.9	91E	9	50G	50K	M
	605	17.1	6.9	12.0					
	750	23.3	10.7	17.6					
DS-22	200	114.3	35.2	74.5	95A	5	50G	50K	M
	650	13.7	7.3	8.9					
	750	0.2	0.8	0.1					
DS-23	200	281.6	57.7	183.7	65A	35	50G	50K	M
	650	35.2	12.5	23.8					
	750	84.2	21.0	57.0					

(continued)

TABLE B-3. (Continued)

Name	Temp (°C)	Force[a] N	Std dev	Strength x 10^4 Pa	Raw materials[b] Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-24	200	268.3	71.8	168.8	65A	35	50G	50K	O
	650	43.4	15.9	25.4					
	750	151.3	34.2	88.7					
DS-25	200	248.2	45.1	131.6	65A	35	20H	80K	M
	650	78.1	14.0	40.1					
	750	151.3	36.6	88.7					
DS-25A	200	111.6	21.0	94.5	65A	35	20H	80K	M
	650	49.6	11.6	33.5					
	750	151.3	36.6	88.7					
DS-26	200	71.2	16.6	40.4	20A	80	80G	20K	N
	650	33.6	8.6	19.7					
	750	120.3	28.2	75.7					
DS-27	200	98.5	22.9	56.8	20B	80	80G	20K	N
	650	51.7	7.1	27.4					
	750	120.3	28.2	75.7					
DS-28	200	180.2	66.0	102.2	50A	50	50H	50K	N
	650	38.8	7.0	23.5					
	750	113.2	23.8	71.2					
DS-30	200	56.4	9.9	41.2	65B	35	50H	50L	O
	650	8.6	7.8	6.5					
	750	8.6	4.4	6.0					
DS-31	200	50.8	12.6	37.1	65A	35	50G	50L	M
	650	8.5	3.1	5.8					
	750	7.8	4.8	5.5					

(continued)

TABLE B-3. (Continued)

Name	Temp (°C)	Force[a] N	Std dev	Strength x 10^4 Pa	Raw materials[b] Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-32	200	166.3	27.3	119.0	65A	35	20H	80L	O
	650	35.3	7.6	22.0					
	750	20.3	3.0	14.3					
DS-33	200	56.8	23.5	35.7	20A	80	10G	90K	M
	650	108.2	32.7	61.3					
	750	94.0	28.5	61.3					
DS-34	200	92.3	17.1	50.6	55A	45	50F	50K	M
	650	17.1	4.5	12.5					
	750	146.1	32.3	85.7					
DS-35	200	86.9	30.1	56.7	65A	35	50G	25I 25L	N
	650	6.9	2.7	4.3					
	750	24.2	8.4	17.0					
DS-36	200	88.6	27.0	69.9	65A	35	50G	25K 25L	N
	650	12.3	4.4	7.0					
	750	19.5	7.0	13.7					
DS-37	200	108.1	16.1	57.3	80A	20	10G	90K	M
	650	35.2	6.9	17.5					
	750	77.8	15.1	39.9					
DS-38	200	146.8	23.1	111.4	55A	45	5G	95K	M
	650	107.1	14.2	69.9					
	750	75.6	25.7	59.6					
DS-39	200	158.3	29.8	115.5	90A	10	80G	20K	M
	650	20.9	3.0	15.8					
	750	6.7	2.3	4.0					

(continued)

TABLE B-3. (Continued)

Name	Temp (°C)	Force[a] N	Std dev	Strength x 10^4 Pa	Raw materials[b] Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-40	200	239.6	32.3	174.9	90B	10	80H	20K	M
	650	21.3	4.1	16.8					
	750	10.0	2.8	6.5					
DS-42	200	127.8	50.0	86.5	65A	35	50H	50L	0
	650	20.1	5.5	15.2					
	750	6.0	3.2	4.5					
DS-43	200	162.9	39.8	98.9	65A	35	35H	65L	M
	650	26.5	6.5	19.3					
	750	11.0	2.4	6.9					
DS-44	200	172.1	30.1	56.7	65A	35	25G 25H	50K	N
	650	29.3	3.1	23.1					
	750	40.3	6.9	28.3					
DS-45	200	72.3	12.4	43.9	80B	20	10H	25K	N
	650	8.5	2.1	4.8					
	750	60.7	17.6	39.6					
DS-23A	200	93.0	17.0	70.6	56A	35	50G	50K	N
	650	17.4	4.1	13.7					
	750	66.5	24.7	48.5					
DS-32A	200	131.0	23.5	95.6	65A	35	50G	50K	M
	650	17.7	4.0	13.4					
	750	19.3	6.0	16.5					
DS-33A	200	97.9	19.3	55.7	20A	08	10G	09K	M
	650	220.3	53.2	124.9					
	750	269.5	42.8	152.8					

(continued)

TABLE B-3. (Continued)

					Raw materials[b]				
Name	Temp (°C)	Force[a] N	Std dev	Strength x 10^4 Pa	Coarse sand	200 mesh sand (F)	Burned dolomite	Limestone	Nepheline syenite (100%)
DS-38A	200	234.3	38.7	128.4	85A	45	5G	95K	M
	650	182.3	29.4	103.3					
	750	238.8	43.7	-					

(a) Indicates average values for ten pellet samples.

(b) Raw Materials (Letter indicates material used in batch).
- (A) PGS Berkeley No. 1 dry sand
- (B) PGS Oklahoma No. 1 dry sand
- (C) PGS Berkeley fine dry special sand
- (D) PGS Berkeley 40 mesh oversize ground sand
- (E) PGS Berkeley 50 mesh oversize ground sand
- (F) PGS Berkeley 200 mesh oversize ground sand
- (G) National Lime and Stone No. 40 burned dolomite
- (H) Ohio Lime No. 100 burned dolomite
- (I) Warner glass grade limestone (16 mesh)
- (J) Warner 50 mesh glass grade limestone (lab prepared)
- (K) National Gypsum York No. 4 limestone (14 mesh)
- (L) Warner pulverized limestone (200 mesh)
- (M) Indusmin 7-330 nepheline syenite (30 mesh)
- (N) Indusmin 7-340 nepheline syenite (40 mesh)
- (O) Indusmin A-200 nepheline syenite (200 mesh)

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TABLE B-4. RAW MATERIALS USED IN DS BATCHES

Raw material	Comments
Berkeley No. 1 dry*	Only 20 x 140 mesh sand studied. Standard in glass industry.
Berkeley fine dry special	A 40 x 325 mesh sand which could not be supplied on a continuing basis.
Berkeley 40 and 50 mesh sands with oversize ground	Experimental sands which could not be supplied on a continuing basis.
Oklahoma #1 dry sand	A 50 x 200 mesh sand with rounded grains that generally caused a decrease in strength.
Berkeley 200 mesh Supersil*	Used to promote preheat strength. Readily available.
Warner 200 mesh limestone	Appeared to cause a decrease in preheat strength.
National Gypsum York #4 limestone*	A 40 x 200 mesh limestone substituted for coarser limestone.
National Lime and Stone #40 burned dolomite*	Standard in the industry. Minus 40 mesh.
Ohio Lime #100 burned dolomite	Minus 100 mesh. No benefit over 40 mesh Burned Dolomite.
Indusmin 330 nepheline syenite	Standard 30 mesh material used in glass industry.
Indusmin 340 nepheline syenite*	Minus 40 mesh grind. Yields slightly better strength results than 30 mesh grind.
Indusmin A-200 nepheline syenite	Minus 200 mesh grind. No benefit over coarser material.

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TABLE B-4. (Continued)

Stauffer dense western soda ash*	Round grain. Used in all tests.
FMC salt cake and Shamokin carbocite*	Standard fining package. May be reduced or removed in actual preheating practice.

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* To be used in MS batches.

TABLE B-5. DATA OBTAINED FROM MARS PELLETIZING RUN MARCH 24, 1978 (Batch DS-18)

Time from start of stable bed	Diameter cm Mesh (in)	Percent of pellets between given diameters <0.6 <1/4	 0.6-1.0 1/4-3/8	 1.0-1.3 3/8-1/2	 1.3-1.6 1/2-5/8	 1.6-1.9 5/8-3/4	 >1.9 >3/4	Compressive strength, x 10^4 Pa Dried at 200°C X	 dia. (cm)	Comments
5			0.5	7.0	38.5	50.1	4.0	73.5	1.5	Started bed with
10			2.5	10.7	37.1	29.5	20.2	67.6	1.7	10% water addition
15			0.3	1.9	16.3	58.8	22.7	85.3	1.8	
20		0.2	13.9	39.9	40.8	4.5	0.6	98.0	1.2	
30			1.0	19.0	76.0	4.0	-	90.2	1.5	Water was gener-
35			1.1	16.5	32.8	49.6	-	53.9	1.4	ally either 10%
40			2.5	12.7	47.1	33.1	4.2	32.3	1.8	or 16%
45		0.5	5.2	10.5	29.6	42.4	12.2	89.2	1.5	
50			0.2	4.1	33.0	49.5	13.2	85.3	1.4	
55			0.4	14.4	40.5	34.8	9.7	98.0	1.5	
60			-	-	3.3	44.9	51.8	117.6	1.5	
				Bed discharged and started again						
0		0.1	35.7	41.1	22.0	1.1	-	126.5	1.1	Water addition to
5			0.9	33.3	65.3	0.5	-	129.4	1.1	start bed was 11.3
10			-	1.1	66.3	32.7	-	172.6	1.5	increased to 12.7%

TABLE B-6. BATCHES CONTAINING ALTERNATE BINDERS

Raw materials	Batch number and percent by weight in batch						
	DS-46	DS-47	DS-48	DS-49	DS-50	DS-51	DS-52
Berkeley No. 1 dry sand	39.1	38.0	39.1	38.0	38.2	38.0	39.1
Berkeley No. 200-mesh supersil	21.1	20.5	21.1	20.5	20.6	20.5	21.1
Indusmin 340 nepheline syenite	7.3	7.1	7.3	7.1	7.1	7.1	7.3
Stauffer soda ash	17.9	17.4	17.9	17.4	17.5	17.4	17.9
No. 100 burned dolomite	-	-	-	-	-	-	4.7
York No. 4 limestone	9.4	14.6	9.4	14.6	9.2	14.6	9.4
Warner burned high-calcium limestone	4.7	1.8	-	-	-	-	-
Kimballton hydrated high-calcium limestone	-	-	4.7	1.8	-	-	-
M. J. Grove hydrated high-calcium limestone	-	-	-	-	6.8	1.8	-
Salt cake	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Carbocite	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Drop-test number	13	5	23	18	11	9	19

(continued)

TABLE B-6. (Continued)

Raw materials	Batch number and percent by weight in batch											
	DS-46			DS-47			DS-48			DS-49		
Strength test result												
Temp,°C	200	650	750	200	650	750	200	650	750	200	650	750
Mean crushing force, N	53.8	6.2	6.6	34.6	4.4	32.9	147.6	20.4	12.8	60.0	8.0	34.6
Standard deviation	11.1	0.8	1.3	5.7	0.4	7.5	26.1	4.8	6.2	8.4	1.7	8.4
Mean strength, psi	106.3	11.5	13.8	71.5	7.7	62.9	205.4	48.6	24.6	248.9	22.2	96.0
Mean strength x 10^4 Pa	73.5	7.8	9.8	49.0	4.9	43.1	209.8	33.33	16.6	101.9	14.7	65.7

(continued)

TABLE B-6. (Continued)

Raw materials	Batch number and percent by weight in batch								
	DS-50			DS-51			DS-52		
Strength test result									
Temp, °C	200	650	750	200	650	750	200	650	750
Mean crushing force, N	140.3	16.9	4.0	116.0	22.6	46.7	87.6	20.4	12.8
Standard deviation	20.9	7.1	1.7	34.6	4.4	8.0	12.4	2.2	6.2
Mean strength, psi	286.8	48.6	11.5	319.6	59.3	136.2	206.4	21.4	38.4
Mean strength x 10^4 Pa	265.7	33.3	7.8	219.6	40.2	93.1	142.2	14.7	26.4

TABLE B-7. (MS) PELLETIZING RESULTS

Batch numbers	MS-0	MS-1	MS-2	MS-2	MS-3	MS-4	MS-5
Coarse sand/fine sand	65/35	70/30	65/35	70/30	60/40	80/20	80/20
Burned dolomite/ limestone	20/80	12.5/87.5	35/65	35/65	50/50	30/70	50/50
Pelletizability	Poor	Poor	Good	Fair	Fair	Poor	No pellets
Pan angle	23°	19-23°	24°	24°	25°	23-25°	24°
Percent moisture addition	10	11-13	12.1	12.9	12.4	12.1	-
Mean drop strength	8	8	10	>25	6	12	-

(continued)

TABLE B-7. (Continued)

Batch numbers	MS-6	MS-7	MS-8	MS-9	MS-10	MS-11	MS-12
Coarse sand/fine sand	70/30	55/45	55/45	62.5/37.5	65/35	65/35	60/40
Burned dolomite/ limestone	50/50	35/65	50/50	42.5/57.5	40/60	35/65	40/60
Pelletizability	Fair	Fair	Fair	Good	Fair	Good	Fair
Pan angle	24°	24°	23°	24.5°	24°	24°	24°
Percent moisture addition	12.6	11.6	11.2	11.5*	12.1	11.8	11.2
Mean drop strength	19	13	9	17	10	13	24

All batches contained approximately: 7.3% nepheline syenite, 17.9% soda ash, 0.5% salt cake, and 0.05% carbocite. Drum speed constant at 43 meters/minute for all batches. Pelletizing water temperature constant at 16°C. Nozzles 2501 and 250067 were used for all tests. Room temperature constant at 18°C. Batch feed rate constant at 332 kg/hr. (* MS-2 percent moisture dropped to 10.6% with 20 ppm Aerosol addition.)

TABLE B-8. DRIED STRENGTH AND WEIGHT LOSS FOR MS-2, MS-6, MS-7, AND MS-8

Batch number	MS-2(a)	MS-2	MS-2	MS-2	MS-6	MS-6
Drying temperature, °C	100	100	100	100	200	200
Drying time, hrs	0.25	0.5	1	4	0.25	0.5
Percent weight loss	2.5	4.0	7.5	9.7(b)	7.3	10.6
Mean crushing force, N	6.8	7.8	34.3	149.0	38.2	80.4
Standard deviation	0.9	0.9	14.7	15.6	11.7	10.7
Mean strength 10^4 x Pa	2.9	4.9	21.5	96.1	25.4	61.7

(continued)

TABLE B-8. (Continued)

Batch number	MS-6	MS-6	MS-6	MS-7	MS-7	MS-8	MS-8
Drying temperature, °C	200	200	20	200	20	200	20
Drying time, hrs	1	16	16	16	16	16	16
Percent weight loss	10.7	10.6	2.3	11.4	1.5	10.2	1.7
Mean crushing force, N	82.3	72.5	19.6	105.9	10.7		
Standard deviation	9.8	11.7	1.9	19.6	1.9	16.6	3.9
Mean strength 10^4 x Pa	50.0	43.1	13.7	50.9	4.9	25.4	8.8

(a) Same composition as MS-11.
(b) Air-dried weight loss 4.5 percent.

TABLE B-9. STRENGTHS AND ABRASION TEST RESULTS FOR BATCHES MS-2, MS-6, MS-7, AND MS-8

Batch number	MS-2[a]			MS-6			MS-7			MS-8		
Temperature, °C	200	650	750	200	650	750	200	650	750	200	650	750
Mean crushing force, N	43.2	13.7	66.6	158.8	24.5	26.4	144.1	47.0	197.1	74.5	20.5	50.0
Standard deviation	8.8	3.9	8.8	29.4	3.9	16.6	25.4	9.8	38.2	25.4	3.8	10.7
Mean strength x 10^4 Pa	29.4	9.8	60.8	98.0	13.7	15.6	65.7	55.8	93.1	51.9	13.7	37.2
Percent abrasion loss	3.0	-	-	5.0	-	-	9.4	-	-	35.0	-	-

(a) Initial MS-2 batch with MS-11 composition.

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TABLE B-10. STRENGTHS AND ABRASION TEST RESULTS FOR BATCHES MS-2, MS-9, MS-10, MS-11, AND MS-12

Batch number	MS-2			MS-9			MS-10			MS-11			MS-12		
Temp. °C	200	650	750	200	650	750	200	650	750	200	650	750	200	650	750
Mean crushing force, N	168.6	15.6	8.8	203.9	23.5	56.8	134.3	21.5	136.3	93.1	17.6	99.0	208.8	40.2	145.1
Standard deviation	23.5	3.[illegible]	0.9	47.0	4.9	19.6	43.1	3.9	32.3	27.4	3.9	30.4	60.8	8.8	43.1
Mean, x 10^4 Pa	123.5	8.8	27.4	107.8	16.6	30.4	86.3	12.7	67.6	64.7	12.7	70.6	115.7	24.5	80.4
Percent abrasion loss	2.6	-	-	-	-	-	4.5	-	-	20.7	-	-	3.9	-	-

TABLE B-11. STRENGTH OF PELLETS STORED AT ROOM TEMPERATURE FOR 5 WEEKS AFTER DRYING AT 200°C

Sample number	1a*	2a	3a	4a	5a	6a	7a	8a	Mean a
Mean crushing force, N	50.2	88.9	135.6	123.2	106.3	120.5	84.0	66.2	96.9
Standard deviation	6.2	21.3	23.5	12.8	19.1	13.7	20.4	12.8	32.4
Average strength, x 10^4 Pa	81.3	101.9	182.4	164.7	157.8	171.6	112.7	89.2	126.5

* a indicates the original dried samples

(continued)

TABLE B-11. (Continued)

Sample number	1b*	2b	3b	4b	5b	6b	7b	8b	Mean b
Mean crushing force, N	59.6	82.2	118.3	130.1	91.1	104.5	84.9	80.0	89.4
Standard deviation	24.4	18.2	28.4	25.3	16.4	32.9	15.1	24.4	28.9
Mean strength, x 10^4 Pa	88.2	121. 6	155.9	147.1	135.3	140.2	115.7	104.9	116.7

* b indicates the sample taken 5 weeks later

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TABLE B-12. SO_2 SAMPLING AND ANALYSIS EQUIPMENT AND PROCEDURES

Sampling

Sampling the flue gas was performed by grab sample collection using a 500 cc glass bulb equipped with Teflon stopcocks and a septum for sample withdrawal. (Alltech Catalog No. 7011)

Analysis

SO_2 analyses were performed by gas chromatography/flame photometric detection. Nominally, 0.2 cc sample from the glass bulb was injected into the gas chromatograph with a Hamilton Gas-Tight syringe.

Gas Chromatograph:	Varian 3700, dual column
Detector:	Dual flame photometric
Column:	36' x 1/8" Teflon, 5 ring polyphenyl ether (12%) and H_3PO_4 (0.5%) on 40/60 chromasorb T
Sensitivity:	10^{-9} MV/A, direct output
Temperature, °C:	Column, 60 (isothermal) Injector, 120 Detector, 120
Gases and Flow Rates, cc/min:	Carrier helium - 88 Burner H_2 - 120 Burner #1 Air - 68 Burner #2 Air - 162
Data Output:	H-P Model 3380A integrator

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TABLE B-13. SO_2 CAPTURE RESULTS (FROM GAS CHROMATOGRAPH READINGS) FOR 7/5/78 TEST*

Sample no.	Description	SO_2 detected (PPM), Sample number	
		1	2
1	Upstream - No SO_2	None detected	
2	Downstream - No SO_2	105	
3	Downstream - SO_2 on 5 min.	48	58
4	Downstream - SO_2 on 15 min.	116	114
5	Downstream - SO_2 on 45 min.	19	18
6	Downstream - SO_2 on 75 min.	170	171
7	Upstream - SO_2 on 75 min.	448	453
8	Downstream - SO_2 on 105 min.	170	165

*Test temperature 600°C, gas flow rate 24.8m^3/hr.

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TABLE B-14. SO_2 CAPTURE RESULTS (FROM GAS CHROMATOGRAPH READINGS) FOR 7/6/78 TEST*

Sample no.	Description	SO_2 detected (PPM), Sample number 1	2	3	4
1	Upstream - No SO_2	10	9		
2	Downstream - No SO_2	91	80		
3	Downstream - SO_2 on 5 min.	191	182		
4	Downstream - SO_2 on 15 min.	258	251		
5	Downstream - SO_2 on 30 min.	273	265		
6	Downstream - SO_2 on 60 min.	257	250		
7	Upstream - SO_2 on 60 min.	501	511		
8	Downstream - SO_2 on 90 min.	364	366		
9	Downstream - SO_2 on 120 min.	369	358		
10	Upstream - SO_2 on 120 min.	572	551	536	531

*Test temperature 300°C, gas flow rate 24.8m^3/hr

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TABLE B-15. SO_2 CAPTURE RESULTS (FROM GAS CHROMATOGRAPH READINGS) FOR 7/7/78 TEST*

Sample no.	Description	SO_2 detected (PPM), Sample number 1	2	3	4
1	Upstream - No SO_2	57	61		
2	Upstream - No SO_2 long tygon tube	41	42	36	
3	Downstream - No SO_2	223	253	242	
4	Downstream - SO_2 on 5 min.	132	131	124	
5	Downstream - SO_2 on 15 min.	178	178		
6	Downstream - SO_2 on 30 min.	194	201		
7	Upstream - SO_2 on 30 min.	463	458		
8	Downstream - SO_2 on 60 min.	200	196		
9	Downstream - SO_2 on 90 min.	233	230		
10	Upstream - SO_2 on 90 min.	638	549	556	536
11	Downstream - SO_2 on 120 min.	222	213		
12	Downstream - SO_2 on basket removed	404	387	395	
13	Upstream - SO_2 on basket removed	348	322	321	

*Test temperature 600°C, gas flow rate 15.6m^3/hr

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TABLE B-16. SO_2 CAPTURE RESULTS (FROM GAS CHROMATOGRAPH READINGS) FOR 7/10/78 TEST*

Sample no.	Description	SO_2 detected (PPM), Sample number 1	2	3
1	Upstream - No SO_2	None detected		
2	Downstream - No SO_2	None detected		
3	Downstream - SO_2 on 5 min.	48	49	
4	Downstream - SO_2 on 10 min.	99	94	
5	Downstream - SO_2 on 30 min.	74	75	
6	Upstream - SO_2 on 30 min.	508	553	546
7	Downstream - SO_2 on 60 min.	122	118	
8	Upstream - SO_2 on 60 min.	537	593	587
9	Downstream - SO_2 on 90 min.	400	393	
10	Downstream - SO_2 on 120 min.	136	134	
11	Upstream - SO_2 on 120 min.	553	550	
12	Downstream - SO_2 off 10 min. after basket removed	None detected		
13	Upstream - SO_2 off 10 min. after basket removed	4		

*Test temperature 600°C, gas flow rate 21.2m^3/hr

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TABLE B-17. SO_2 CAPTURE RESULTS (FROM GAS CHROMATOGRAPH READINGS) FOR 7/11/78 TEST*

Sample no.	Description	SO_2 detected (PPM), Sample number 1	2	3
1	Downstream - No SO_2	None detected		
2	Upstream - No SO_2	None detected		
3	Downstream - SO_2 on 5 min.	109	104	104
4	Downstream - SO_2 on 10 min.	99	97	
5	Upstream - SO_2 on 15 min.	586	578	
6	Downstream - SO_2 on 30 min.	127	128	
7	Downstream - SO_2 on 60 min.	110	109	
8	Upstream - SO_2 on 60 min.	504	507	
9	Downstream - SO_2 on 90 min.	154	148	
10	Upstream - SO_2 on 90 min.	528	533	527
11	Downstream - SO_2 on 120 min.	142	139	
12	Upstream - SO_2 on 120 min.	469	482	476

*Test temperature 800°C, gas flow rate $24.8 m^3/hr$

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APPENDIX C

PILOT PLANT DRAWINGS AND CALCULATIONS

DESIGN CRITERIA

Pellet Properties

Information on pellet properties was collected from the bench scale and Columbia Gas tests.

Table C-1 summarizes the pellet properties used in this design.

TABLE C-1
PELLET PROPERTIES

1.	Specific heat of pellets vs. temp. and also heat of reaction, and temp. at which reactions take place.	It was decided to use a design value of 1256 J/kg°C for pellets up to 600°C. and 1675 J/kg°C for pellets above 600° C. This high value will compensate for the heat of reactions, which seem to take place above 600°C.
2.	Size distribution of pellets.	The nominal is 1.27 cm diameter; 95% of the pellets were between .95 cm and 1.59 cm.
3.	Porosity of pellets	40% voids.
4.	Bulk density of dry pellets.	1200 kg/m^3
5.	Max. allowed drying rate, or drying temperature	Drying temperature should not exceed 350°C.
6.	Pellets moisture content.	About 12%.
7.	Wet and dry pellets compression strength.	There are data as a function of temperature.
8.	Specific heat of wet pellets, and laten heat during drying.	There are data available from the Columbia Glas Work

DRYERS

Belt Dryer--

The belt dryer is composed of three compartments, each of which includes a bed of pellets 7.6 cm (3") high, through which drying air is flowing.

The most suitable correlation for the calculation of a heat transfer coefficient seems to be the following:

$$h = 0.584 \frac{C_p \mu}{Dp} Re^{0.7} PL^{2/3}$$

Where:

$$Re = \frac{\rho D_p V}{\mu}$$

$$P_L = \frac{C_p \mu}{K}$$

From experience, it was assumed that an air velocity of about 0.9 m/sec (3 ft/sec.) will be good for this case. It was also known that a temperature of about 300°C. for the first compartment (gas inlet side) is sufficient. Knowing these data h can be estimated.

The amount of water to be removed is known. The drying air comes from a natural gas burner so its water content will be less than 17%. This means that the dew point is about 65.5°C (it is roughly constant along the dryer). This last fact limits the pellets temperature to approximately the same range. To allow a safe margin for errors, it was assumed that the pellets will be heated to 93°C in the belt dryer. Thus, the amount of heat to be transferred is known, and the heat transfer area can be calculated. Knowing the specific area per unit volume of this bed to be about 262 m^2/m^3, the cross section of the belt needed was calculated. When a decision was made to use an 0.6 meter (2 ft.) wide belt, it was found that a 2.4 meter (8 ft) length is sufficient to remove 25% of the water content from 955 Kg/hr (2100 lb/hr) of pellets

Three compartments were used so that in the second compartment most of the drying atmosphere will be recirculated, thus reducing the amount of drying atmosphere that will have to be supplied. The savings in fuel during the assumed test periods will be significant.

The pressure drop through the bed will be approximately 1.27 cm w.c. or less. The atmosphere to the belt will be supplied at 5.08 cm w.c., and a recirculating fan will pull gas from the first and second compartments. It is assumed that by adjusting the control valves to the inlet and outlet of these two points, it will be possible to minimize the leakages of gas through the exit of the belt. (which is impossible to entirely seal.)

An additional fan will be pulling a portion of the gas through the third compartment to the vent. Again by adjusting the control valves between the two fans, it will be possible to minimize the leakage through the inlet of the belt to the third compartment.

Shaft Dryer--

The sizing of the shaft dryer was based on the Columbia Gas pilot plant shaft dryer built and tested previously. This unit was tested with 227 Kg/hr (500 lb/hr) of pellets. Its diameter was .46 m I.D. and the bed height was 2.2 meters. Since this unit was proved to complete good drying, it was decided to design the new unit by scaling up this one.

The criteria for scale-up were chosen to keep the same flow velocity of gas at the same blow ratios.

Translating this into mathematical terms:

$$\frac{(D_2)^2}{(D_1)^2} = \frac{M_{p2}}{M_{pi}}$$

Where D_1 and MP_1 are, respectively, the diameter and the pellet flow rate of the original shaft dryer; D_2 and MP_2 are, respectively, the diameter and pellet flow rate of the new dryer.

It was found that a .914 m I.D. will be needed. The bed height in the new dryer will be the same.

The criteria for sizing the shaft dryer cooling section were as follows:

1. The temperature of the pellets at exit should be a maximum of 100°C.

2. The blow ratio at the cooling section will be 2.

3. The temperature of the pellets entering the cooling section will be 172°C.

4. The blow ratio of the gases at the drying section will be 3.

5. The heat transfer analysis is similar to that for the preheater.

Based on these assumptions, it was found that a 0.9 meter (3 ft) height is needed to cool the pellets to 100°C. The cold air (blow ratio of 2) will cool the pellets and then will be mixed with hot gas (blow ratio of 1) at 350°C to form a drying atmosphere with a blow ratio of 3 about 172°C.

The sizing of the supply lines for cold air and hot gas, as well as for the blower, is such that variations in flow rates are possible in each direction, to compensate for large deviations from the design point.

PREHEATER

Thermal Analysis--

The general energy relationship in a moving bed reactor at thermal equilibrium is:

$$Q_{gas} = Q_{pellets} + Q_{loss} \qquad (1)$$

It was found experimentally that the heat losses from the system are negligible, therefore it can be simplified to the form:

$$Q_{gas} = Q_{pellets} \qquad (2)$$

The basic system under consideration is shown in Figure C1:

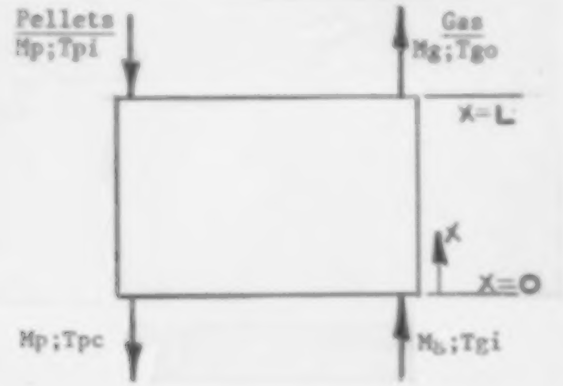

Figure C1 Thermal Analysis Model

Mp;Tpc Mg;Tgi

Equation (2) can be written as follows:

$$\frac{MgCpg}{A} (Tgi-Tgo) = \frac{MpCpp}{A} (Tpo-Tpi) \qquad (3)$$

Equation (3) can be written between the bottom plan of the reactor and any arbitrary elevation in the bed (X):

$$\frac{MgCpg}{A}(Tgi-Tg) = \frac{MpCpp}{A}(Tpo-Tp) \qquad (4)$$

The rate of heat transfer between the gas and the pellets at height X can be written as follows:

$$\frac{MpCpp}{A}\frac{dTp}{dx} = -hv\,(Tg-Tp) \qquad (5)$$

hv is the volumetric heat transfer coefficient, and is dependent on the relative gas velocity, pellet diameter, bed porosity, and gas temperature.

Equations (4) and (5) can be solved, and give the reactor height needed for specific boundary conditions.

$$L = \frac{1}{B(K-1)}\ \mathrm{Ln}\ \frac{Tpo + \dfrac{Tgi-KTpo}{K-1}}{Tpi + \dfrac{Tgi-KTpo}{K-1}} \qquad (6)$$

Where:

$$K = \frac{MpCpp}{MgCpg} \qquad (7)$$

$$B = \frac{hvA}{MpCpp} \qquad (8)$$

hv was calculated based on experimental data. A graph of Nu (which includes hv) as a function of Re is given in the Columbia Gas report, as well as a mathematical relation. Hv is related to Nu number as follows:

$$Nu = \frac{hv\ D^2}{6(1-P)k_g} \qquad (9)$$

The specific heat of the pellets is also known and the gas properties are available for each temperature. Curve fittings were prepared for all the properties enabling a computer program to be used.

Pressure Drop Calculations--

The pressure drop across the bed is calculated using the Darcy equation:

$$H_L = f\ \frac{L}{Dp}\ \frac{\rho V^2}{2g} \qquad (10)$$

Jet Pump

The design of the jet pump in Figure C-2 is based on the conservation of momentum:

momentum input = momentum output

$$\frac{WjVt}{g} + 0 = \frac{WtVt}{g} P_T A_T \qquad (11)$$

Where: Wt is total flow of jet air (Wj lb/hr) plus the induced flow (Ws lb/hr).

Vj, Vt are the linear velocities at the nozzle and throat respectively.

The static pressure at J is assumed to be the reference plane and therefore zero.

Between T and D the air stream is slowed down and the velocity at T is converted into static pressure at D. Thus:

$$\frac{P_T}{\rho_T} + \frac{VT2}{2g} = \frac{PD}{\rho_D} + \frac{VD^2}{2g} \qquad (12)$$

The following assumptions are made:

1. $V_D 2 << V_T 2$
2. $VJ2 = 2g \frac{P_J}{\rho_J}$

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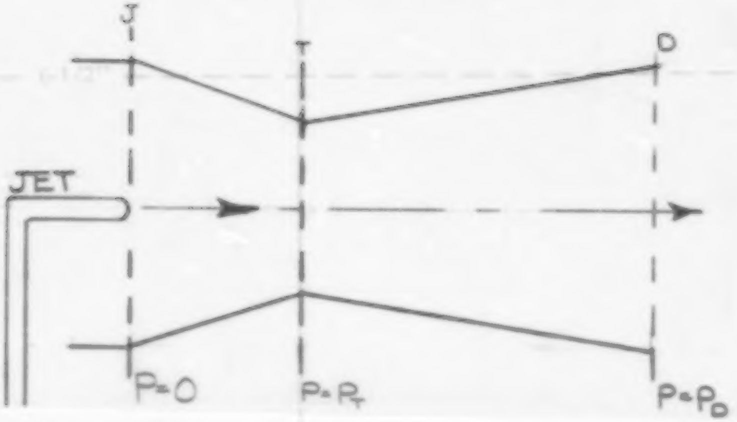

Figure C 2. Jet Pump

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The coefficent f is given as a function of Re. The experimental values of f show that for a moving bed with small amounts of fines and dust, the pressure drop is smaller than for a fixed bed. For moving beds with high amounts of fines and dust, the pressure drop is comparable to that in the fixed bed.

In each case the two values for the pressure drop were calculated, since at this stage it is not known what the nature of the pellet bed will be. In all the calculations, bed diameters were assumed and bed height and pressure drops were calculated. Since many possible designs exist for pre-determined boundary conditions, the actual bed diameter will be chosen as was explained previously in this report.

All the equations and curve fittings for the gas and pellet properties were fed to a Hewlett Packard Model 9820 computer program.

Using this calculation format, a parameter study was done on the effect of changing parameters on the preheater size. The parameter study included:

1. Analysis of paralleled flow vs. counter flow in the preheater. It was found that the counter flow preheater will result in much better thermal efficiency.

2. Analysis of pressure drop and reactor height vs. pellet size. It was found that the larger the pellet diameter, the smaller the pressure drop in the reactor; however a higher reactor is needed. Quantitatively, for the calculated case, it was found that decrease in nominal pellet diameter from .63 to 1.27 cm will increase the pressure drop by 22% and will decrease the bed height required by 42%.

3. Analysis of pressure drop and reactor height vs. pellet uniformity. The voidage in the bed is a good indicator of the pellet size distribution. The nominal voidage is about 40%. It was found that change of ±10% in voidage will change the required bed height and the pressure drop by about 8%.

4. Analysis of pressure drop and bed height vs. wind flow rate. This analysis is directly for sizing the pellets bed in the preheater.

5. Analysis of pressure drop and bed height for bed diameters between .3 and 1.22 m. The .91 m diameter was chosen to be optimal.

It was decided that the preheater should have the capability of preheating pellets to the desired temperature over the following range of parameters:

Pellet flow rate up to = 500 Kg/hr (1100 lb/hr)
Wind inlet temp. = 410°C. to 810°C.
Wind flow rate = 1136 Kg/hr (2500 lb/hr) to 1820 Kg/hr (4000 lb/hr)

Once the ranges of the parameters were decided upon, the bed height needed for each case and the pressure drop in the bed were calculated. The results are presented in Figure C-3 (All the calculations are for a bed diameter of .91 m.). On the right side of Figure C-3, the bed height needed is plotted vs. wind flow for three different wind inlet temperatures. The highest bed is needed when high temperature gas is used at the lowest feed rate, in this case a 2.5 meter (8.3 ft) height is needed. The pressure drop in the bed for the same cases appears on the left side of Figure No. C-4. Two curves are shown for each temperature. The lower one is calculated with the assumption that a small amount of dust is included in the bed, and the higher one for the case of a high amount of dust. The actual pressure drop will be somewhere in between.

Based on the results in Figure C-3, a bed height of 3 meters (10 ft) was chosen. The pressure drops in the bed were recalculated for each flow rate and the maximum expected pressure drops vs. the wind flow are plotted in Figure C-4. The pressure drops in Figure C-3 were considered for sizing the blower for the system.

For a bed with a 3 ft diameter and a 3 meter (10 ft) height, the pellets average residence time is about 288 min (4.8 hrs) for a pellet flow of 500 m/hr. When the gas is fed at 810°C and 1500 m/hr, the pellets will be at a temperature higher than 600°C about 216 min out of the 288 min.

By adding cold air about 0.8 meters (2 1/2 ft) below the top of the bed, the pellets will "see" for about 1 hour, a gas temperature of less than 300°C. This configuration will enable, when desired, an evaluation to be made of the effect of low temperature pollutant absorption by the pellets.

The sizing of the pipe at the inlet from the charge hopper to the preheater was checked by calculating the total pressure drop of the system up to the top of the preheater. Assuming the same pressure drop across this pipe, the leak rate was calculated. The results are presented in Figure C-5.

For example, if the wind flow rate is 1820 Kg/hr (4000 lb/hr) at an inlet temperature of 810°C the system pressure drop will be 33 in w.c. and the leak through this pipe will be 155 Kg/hr (340 lb/hr) which is less than 10% of the wind flow.

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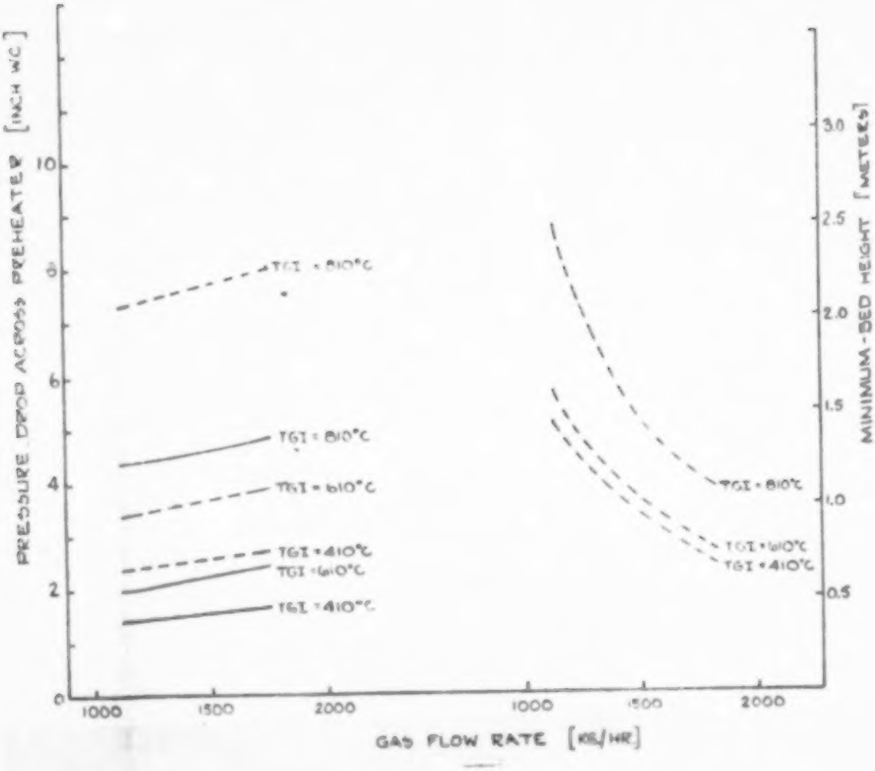

Figure C 3. Pressure drop and bed height versus gas flow rate.
Bed diameter = 3 ft.
Gas inlet temperature indicated near each curve.
Pellets exit temperature = 10°C below gas inlet temperature.

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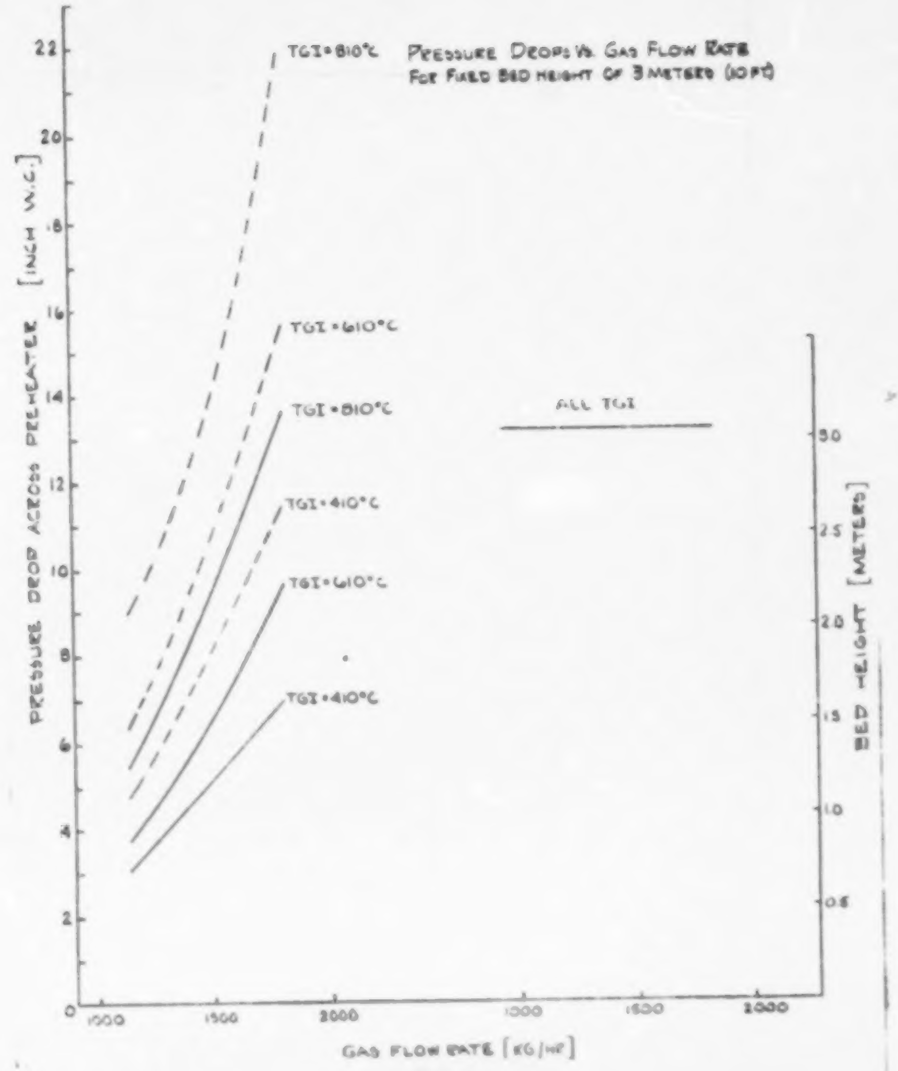

Figure C 4. Pressure drop vs. gas flow rate.

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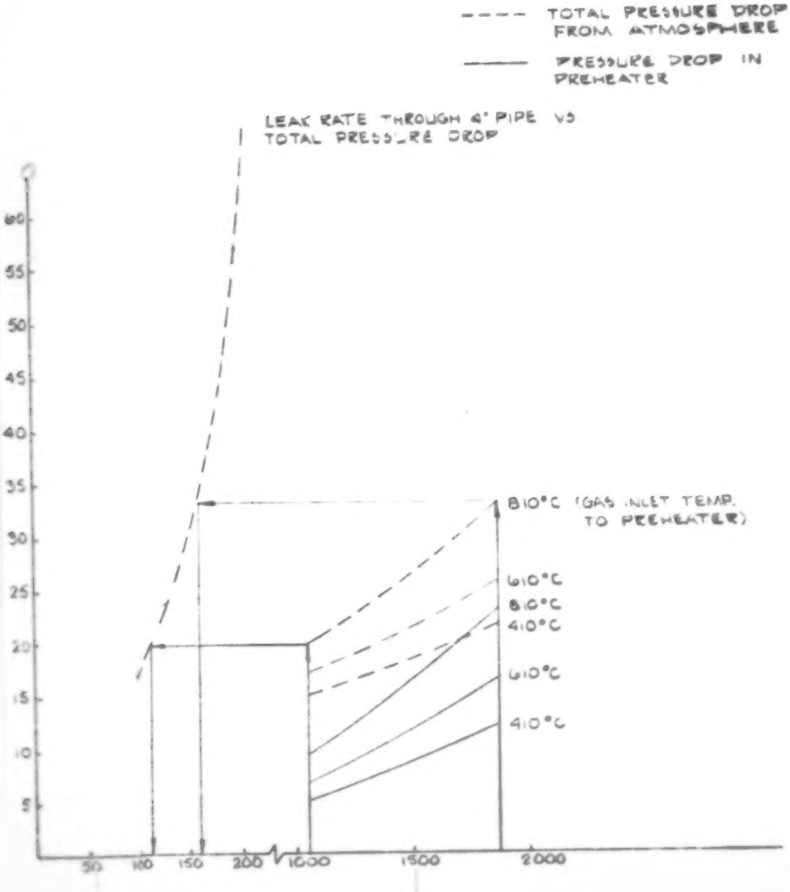

Figure C 5. Estimate of leak rate through the surge hopper.

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The final equation will be:

$$Z^2 = \frac{\rho_T}{\rho_J}\frac{A_T}{A_J}\left[2-\frac{A_T}{A_J}\frac{P_D}{P_J}\right]$$

Where:

$$Z = \frac{W_T}{W_J}$$

This last equation was used, together with the heat balance on the two streams, to size the jet pump and calculate the jet pressure and flow rate requirements for the range of operation required.

The results over the entire range of operating conditions are summarized in Table C-2.

TABLE C-2. JET PUMP CALCULATIONS

Mixture				Cold air (jet)			Hot gas				Pump output ratio E
Flow rate Kg/hr	Flow rate lb/hr	Temp. (°F)	Temp. (°C)	Exit pressure (w.c.)	Flow rate Kg/hr	Flow rate lb/hr	Pressure (psig)	Velocity m/sec	Flow rate kg/hr	Flow rate lb/hr	
1818.2	4000	572	300	6.4	1490.5	3279	1.35	125.8	327.7	721	1.22
1363.6	3000	572	300	3.6	1117.7	2459	0.76	94.3	246	541	1.22
1136.4	2500	572	300	2.5	931.4	2049	0.53	78.6	205	451	1.22
1818.2	4000	842	450	5.1	1382.7	3042	1.16	116.7	435.5	958	1.315
1363.3	3000	842	450	2.9	1036.8	2281	0.65	87.5	326.8	719	1.315
1136.4	2500	842	450	2.0	864.1	1901	0.45	73.0	372.3	599	1.315
1818.2	4000	1202	650	2.8	1153.2	253.7	0.81	97.3	665	1463	1.577
1363.6	3000	1202	650	1.6	864.5	1902	0.46	73.0	499.1	1098	1.577
1136.4	2500	1202	650	1.1	720.5	1585	0.32	60.8	420.5	915	1.577
1818.2	4000	1562	850	0.66	904.1	1989	0.49	76.3	914.1	2011	2.011
1363.6	3000	1562	850	0.37	788.2	1492	0.28	57.2	685.5	1508	2.011
1136.4	2500	1562	850	0.26	565	1243	0.19	47.7	571.4	1257	2.011

SPECIFICATIONS

Pelletizer

Throughput = 2100 lbs/hr,
Pan diameter = 4-6 in I.D.,
Pan depth = 14 and 18 in,
Pan speed = 5.6 to 16.8 RPM variable,
Pan angle = 40°-60° variable.

Dryer System

Belt Dryer--
Temp: 350°C,
Pressure: Atmospheric,
Belt speed: Variable (0.33-1.33 ft/min).
(See Fig C-6)

Shaft Dryer--
SS Refractory lined top charging from belt dryer. Max. temperature 250°C. Cooling air supplied at discharge, two level sensors.
(See Fig C-7)

Excess Air Burners--
T = 600 - 1320°C, 900 lbs/hr flow,
Heat output: 240,000 to 615,000 Btu/hr,
(See Fig C-6, Items EAG - 1000 - LTA, B).

Cold Air Blower--
1.5 psig, 17°C, 3300 cfm, 40 HP,
3500 rpm, 440 V.
(See Fig. C-6, Item B-101).

Circulation Fan--
5 in w.c., 1620 scfm, 200°C.,
(See Fig. C-6, Item RF-102).

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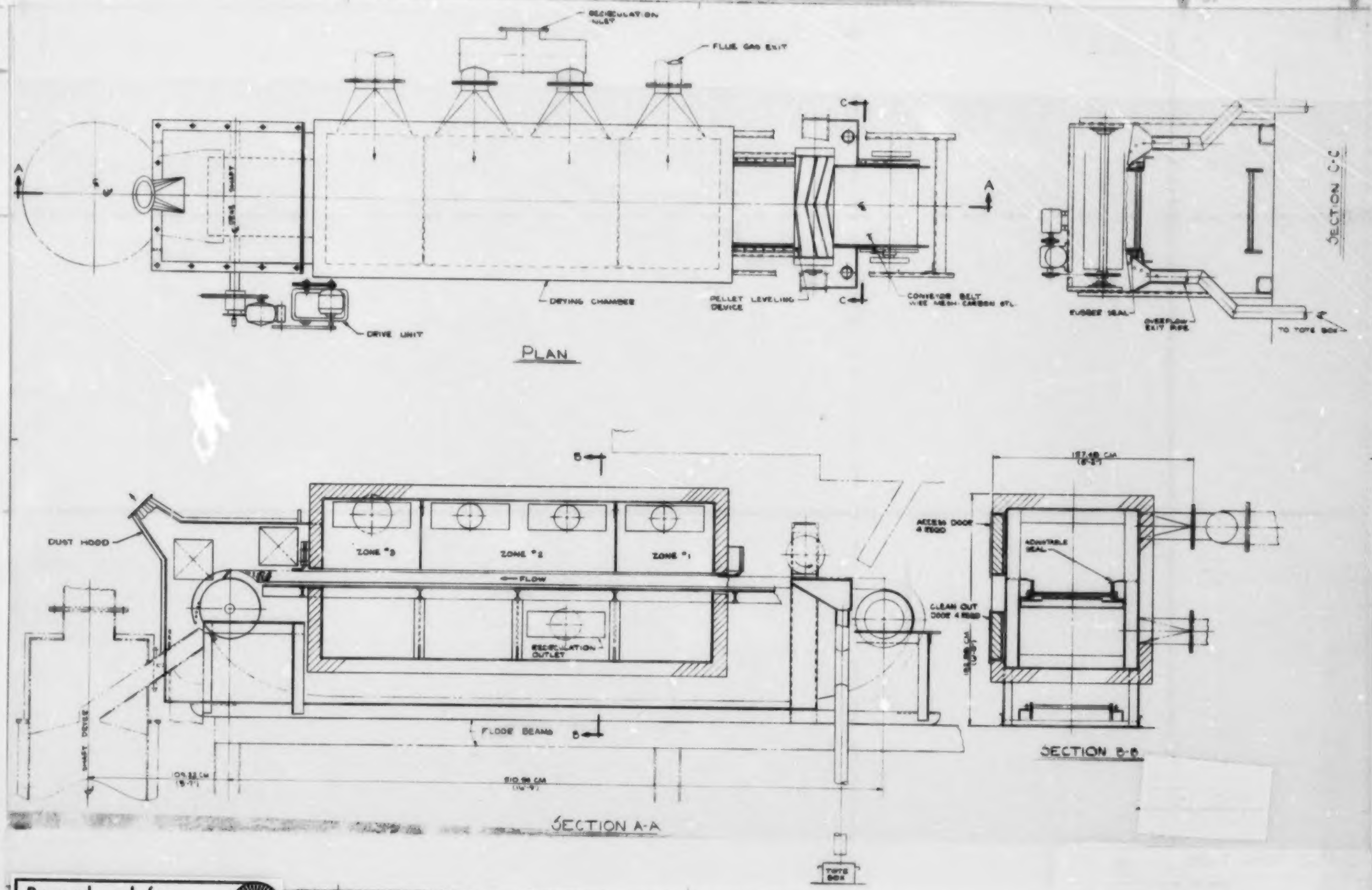
RECIRCULATION INLET
FLUE GAS EXIT
DRYING CHAMBER
PELLET LEVELING DEVICE
CONVEYOR BELT WIRE MESH CARBON STL.
DRIVE UNIT
PLAN
SECTION C-C
RUBBER SEAL
OVERFLOW EXIT PIPE
TO TOTE BOX
DUST HOOD
ZONE #3
ZONE #2
ZONE #1
FLOW
RECIRCULATION OUTLET
FLOOR BEAMS
SECTION A-A
ACCESS DOOR 4 REQD
ADJUSTABLE SEAL
CLEAN OUT DOOR 4 REQD
SECTION B-B
TOTE BOX

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Figure C 6. Belt dryer detail.

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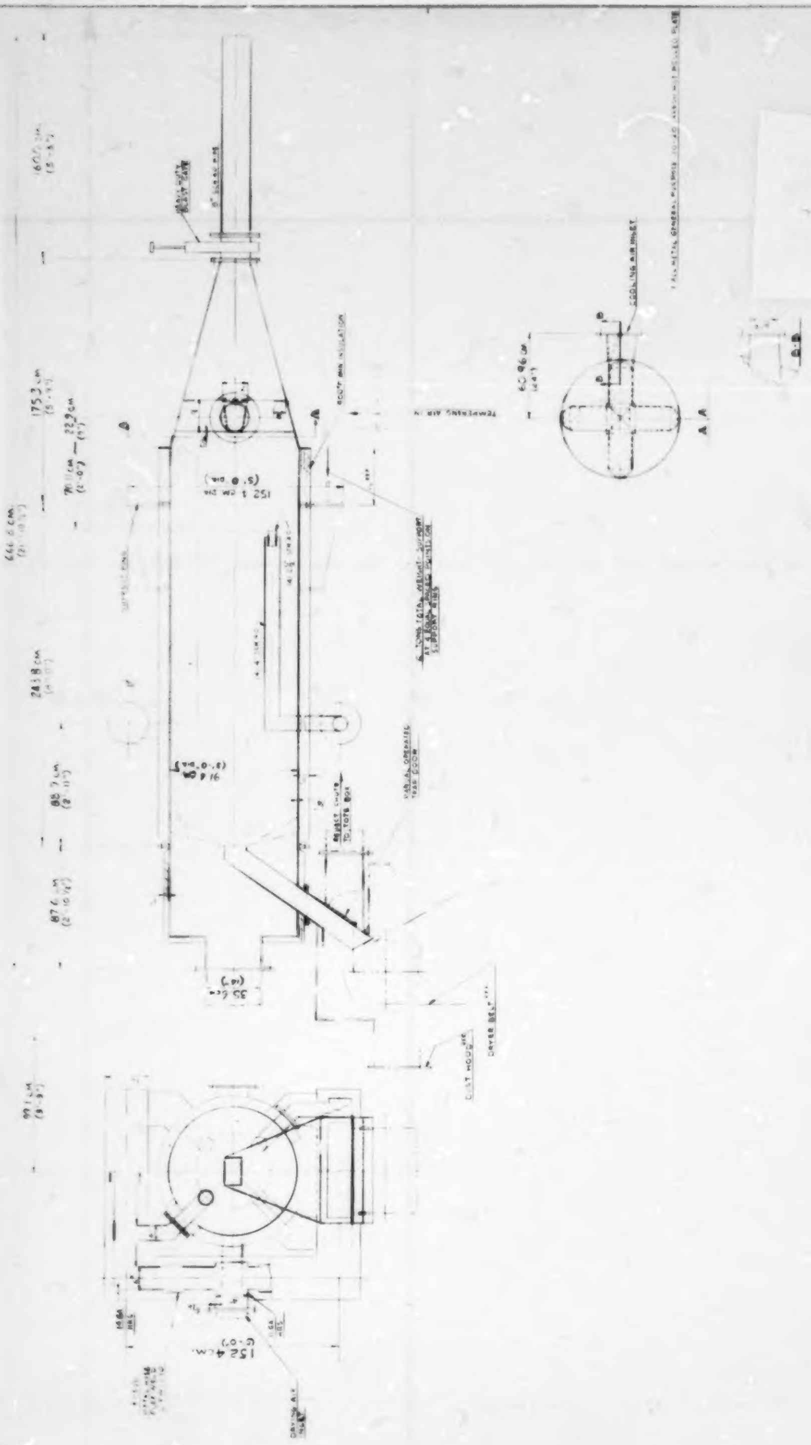
TEMPERING AIR IN
COOLING AIR INLET
A-A
B-B

Figure C 7. Shaft dryer detail.

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Exhaust Fan--
900 cfm, 3 in w.c., 250°F,
(See Fig. C-6, Item EF-103).

Flow Control Valves--
(See Fig. C-8).

HCV-4 HCV-5	Flow control valve (cold air).	Max. flow rate 1800 lbs/hr, 5 in diameter.
HCV-6 HCV-7	Flow control valve (cold air).	Max. flow rate 3100 lbs/hr, 6 in diameter.
HCV-3	Flow control valve (cold air).	Max. flow rate 5000 lbs/hr, 10 in diameter.
HCV-9	Flow control valve (at propeller).	Max. flow rate 4500 lbs/hr, Temp. = 110°C, Wheel diameter = 24 in
HCV-8	Flow control valve (at circulation fan).	Max. flow rate 4500 lbs/hr, 10° diameter, Temp. = 200°C.

Temperature Control--
(See Fig. C-6)

TCV-1	Temperature control valve (fuel).	Max. flow 460 lbs/hr, Diameter = 1.0 in Torque requirements 40 ft - lb, 40 sec., 120 V, AC, 60 Hz 1000 phase slidewire.
TCV-2	Temperature control valve (fuel).	Max. flow 600 lbs/hr, Dia. = 1.0 in
TC-1 TC-2	Temperature control (from Burner #1 and #2).	Input type J thermocouple, Range: 0-1600°F, 170 V, AC, output PB 5-500%. Reset 0.02-2 rpm. Rate 0-1 min.

Level Control--
(See Fig. C-6)

LE-22 A	Level control (high).	Pellets level in dryer, on-off only, max. temp. 600°F.
LE-22 B	Level control.	Pellets level in dryer, on-off only, max. temp. 660°F.

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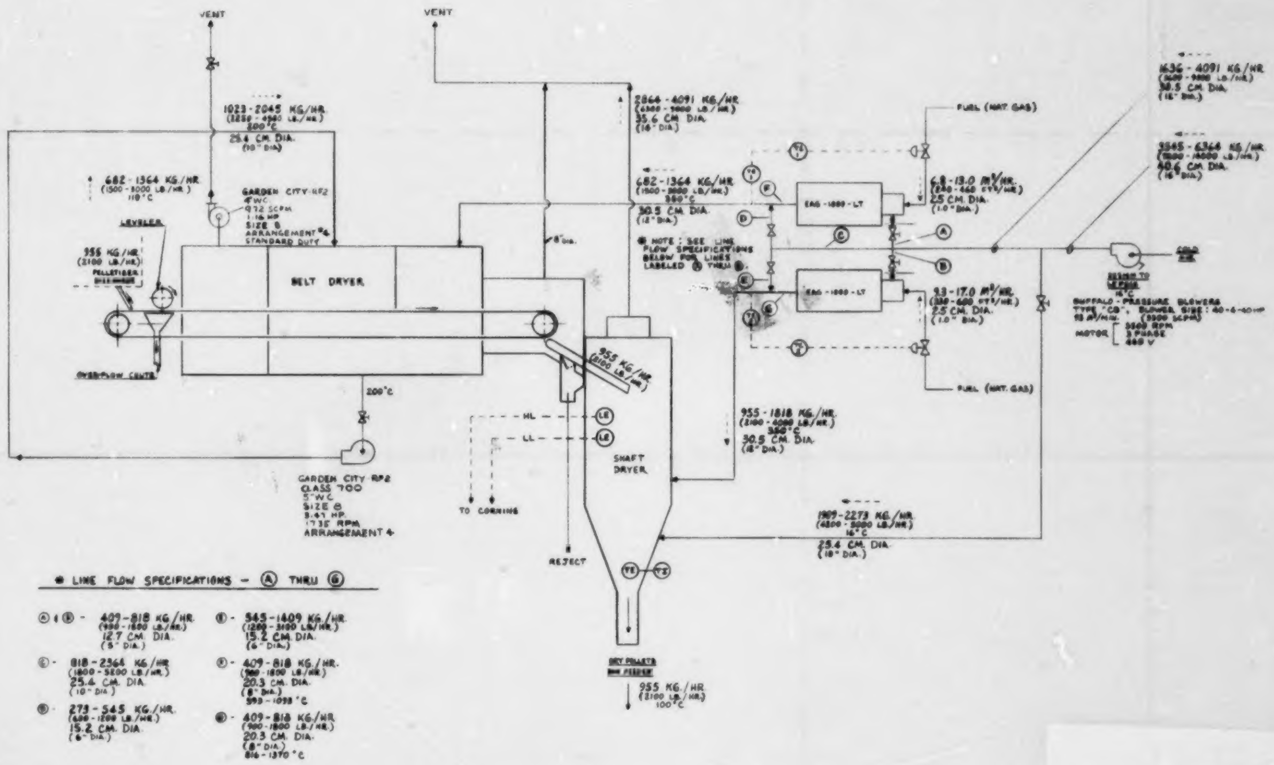
VENT
VENT
1023-2045 KG/HR.
(2250-4500 LB./HR.)
200°C
25.4 CM. DIA.
(10" DIA.)
682-1364 KG./HR.
(1500-3000 LB./HR.)
110°C
GARDEN CITY RF2
4"WC
972 SCFM
1.16 HP
SIZE 8
ARRANGEMENT #4
STANDARD DUTY
LEVELER
955 KG/HR.
(2100 LB./HR.)
PELLETIZER DISCHARGE
OVERFLOW CHUTE
BELT DRYER
200°C
GARDEN CITY RF2
CLASS 700
5"WC
SIZE 8
3.47 HP.
1735 RPM
ARRANGEMENT 4
2864-4091 KG/HR
(6300-9000 LB./HR.)
35.6 CM DIA.
(14" DIA.)
682-1364 KG/HR
(1500-3000 LB./HR.)
350°C
30.5 CM. DIA.
(12" DIA.)
8" DIA.
* NOTE: SEE LINE FLOW SPECIFICATIONS BELOW FOR LINES LABELED Ⓐ THRU Ⓖ.
955 KG./HR.
(2100 LB./HR.)
HL
LL
LE
LE
TO CORNING
REJECT
SHAFT DRYER
TE
TI
DRY PELLETS
955 KG./HR
(2100 LB./HR.)
100°C
955-1818 KG./HR.
(2100-4000 LB./HR.)
350°C
30.5 CM. DIA.
(12" DIA.)
1909-2273 KG./HR.
(4200-5000 LB./HR.)
16°C
25.4 CM. DIA.
(10" DIA.)
EAG-1000-LT
EAG-1000-LT
FUEL (NAT. GAS)
FUEL (NAT. GAS)
6.8-13.0 M³/HR.
(240-460 FT³/HR.)
2.5 CM. DIA.
(1.0" DIA.)
9.3-17.0 M³/HR.
(330-600 FT³/HR.)
2.5 CM. DIA.
(1.0" DIA.)
Ⓐ
Ⓑ
Ⓒ
Ⓓ
Ⓔ
Ⓕ
Ⓖ
1636-4091 KG/HR
(3600-9000 LB./HR.)
30.5 CM. DIA.
(12" DIA.)
3545-6364 KG/HR
(7800-14000 LB./HR.)
40.6 CM. DIA.
(16" DIA.)
COLD AIR
16°C
BUFFALO-PRESSURE BLOWERS
TYPE "CB", BLOWER SIZE: 40-4-40HP
93 M³/MIN. (3300 SCFM)
MOTOR 3600 RPM 3 PHASE 460 V
* LINE FLOW SPECIFICATIONS - Ⓐ THRU Ⓖ
Ⓐ & Ⓑ - 409-818 KG/HR. (900-1800 LB./HR.) 12.7 CM. DIA. (5" DIA.)
Ⓒ - 818-2364 KG/HR (1800-5200 LB./HR.) 25.4 CM. DIA. (10" DIA.)
Ⓓ - 273-545 KG./HR. (600-1200 LB./HR.) 15.2 CM. DIA. (6" DIA.)
Ⓔ - 545-1409 KG./HR. (1200-3100 LB./HR.) 15.2 CM. DIA. (6" DIA.)
Ⓕ - 409-818 KG./HR. (900-1800 LB./HR.) 20.3 CM. DIA. (8" DIA.) 593-1093 °C
Ⓖ - 409-818 KG./HR (900-1800 LB./HR.) 20.3 CM. DIA. (8" DIA.) 816-1370 °C

Figure C 8. Dryer system P and I diagram.

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Temperature Indicators--
(See Fig. C-6).

TE-1	Temperature element (from burner #1 and #2).	Type J thermocouple 12 in long with aluminum twist-cap head, Inconel 600 sheath.
TE-2		
TE-18	Temperature elements.	Thermocouple type K wire size, AWG 14 Inconel protection tube 18 in long.
TE-19		
TE-20		
TE-21		
TE-23		
TE-26		
TE-27		
TE-30		

Flow Indicators--
(See Fig. C-6).

FI-10	Flow indicator.	Natural gas flow rate, up to 600 ft^3/hr.
FI-13	Flow indicator.	
FI-12	Flow indicator. Orifice and DP cell.	Max flow 5000 lb/hr, Pressure: up to 1.5 psig, Remote reading.
FI-11		
FI-15		
FI-16		
FI-25		
FI-29		
FI-31		

Pressure Indicators--
(See Fig. C-6).

PI-14	Pressure indicators.	Pressure up to 1.5 psig, temp. up to 700°F.
PI-17		
PI-24		
PI-28		

Temperature Recorder--
(See Fig. C-8).

TR-32	Temperature recorder.	10 point recorder, Temp. up to 700°F.

Preheater System

Shaft Preheater

C.S., lined with silica bricks, and includes a chunk breaker. Max. temperature of 1577°F, pressure ambient to -30 in w.c. (See Fig. C-9).

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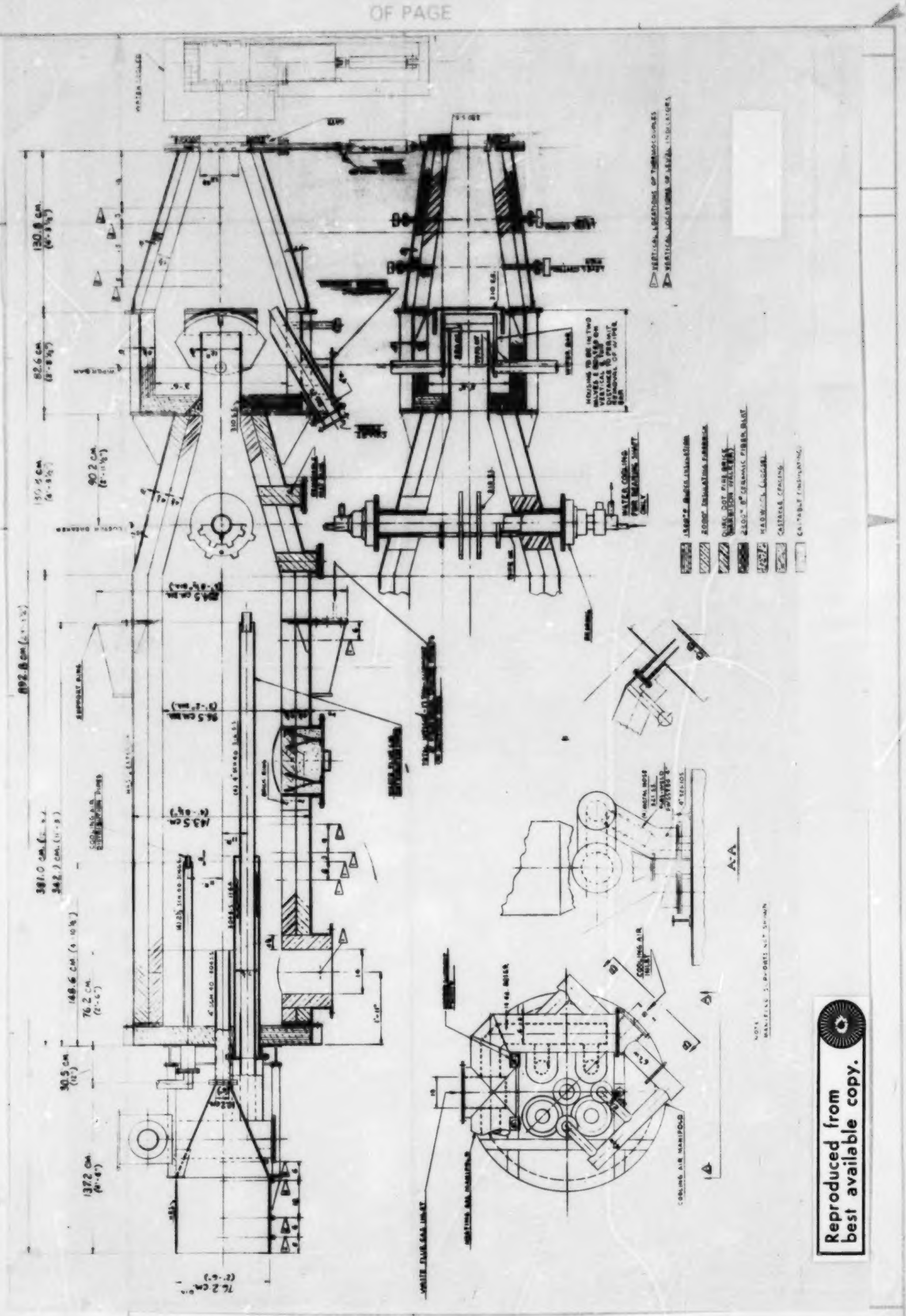
130.8 cm
82.6 cm
90.2 cm
892.8 cm
381.0 cm
342.9 cm
148.6 cm
76.2 cm
30.5 cm
137.2 cm
76.2 cm
A-A

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Figure C 9. Shaft preheater detail.

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Sealing Chamber (Charge Hopper)--

Maximun temperature, 700°F, pressure atmospheric connected to the preheater through 4 in I.D. pipe S.S. (See Fig. C-9).

Mixing Chamber--

S.S., lined with silica bricks, and includes a wiper-bar feeder, a cullet inlet line, and four level sensors.

Max. temp: 1572°F,
Pressure: ambient,
(See Fig. C-9).

Jet Pump--

Hot gas inlet temp: 2642°F,
Exit gas max. temp. 1562°F,
Jet max. pressure: 2 psig,
Throat to nozzle area ratio = 10:1,

The internal surface will be refractory material, abrasion resistant (high alumina) nozzle with water cooled S.S. (See Fig. C-10).

Ambient Air Blower--

BHP = 30 HP, max. pressure - 2 psig,
Max. flow = 9000 lbs/hr
(2000 scfm),
Ambient Temperature,
(See Fig. C-10, Item B-100).

I.D. Fan--

BHP = 52 HP,
Min. pressure at suction = -37 in w.c.,
Max. flow rate = 10,000 lbs/hr
(2200 scfm),
Max. temperature = 572°F,
(See Fig. C-10, Item B-101).

Flow Control Valve--

Max. flow rate = 10,000 lbs/hr,
(2200 scfm), pipe diameter 14 in,
Max. temp. = 572°F,
Pressure drop at max. flow <10 in,
Actuator,
(See Fig. C-10, Item FCV-2).

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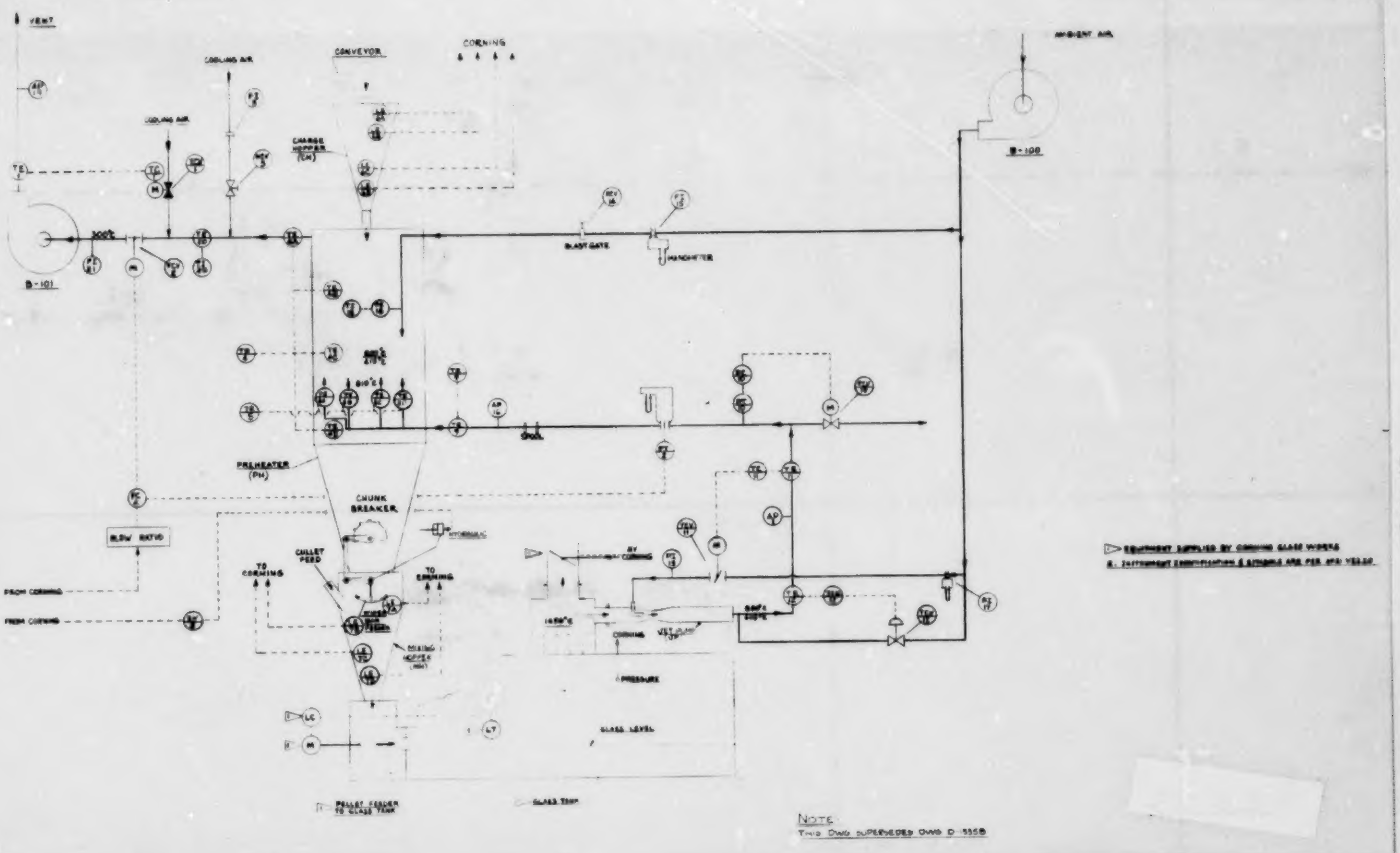
VENT
COOLING AIR
COOLING AIR
CONVEYOR
CORNING
AMBIENT AIR
CHARGE HOPPER (CH)
B-101
B-100
BLAST GATE
MANOMETER
PREHEATER (PH)
CHUNK BREAKER
HYDRAULIC
CULLET FEED
TO CORNING
TO CORNING
BLOW RATIO
FROM CORNING
FROM CORNING
MIXING HOPPER (MH)
BY CORNING
CORNING
JET PUMP
PRESSURE
GLASS LEVEL
PELLET FEEDER TO GLASS TANK
GLASS TEMP
EQUIPMENT SUPPLIED BY CORNING GLASS WORKS
NOTE:
THIS DWG SUPERSEDES DWG D-5558

Figure C 10. Preheater system r and I diagram.

Temperature Control Valves--
(See Fig. C-8)

TCV-1	I.D. fan temp. control valve (for emergency).	8 in valve on-off control for emergency, temp. up to 600°F, fail open, motor operated.
TCV-11	Temp. control valve.	Diameter 6 in I.D., Max. flow rate = 3250 lbs/hr, (720 scfm), Max. temp. - ambient, Max. inlet pressure = 2 psig, Pressure drop at max. flow rate: 2 in w.c., Actuator.
TCV-12	On-off valve for emergency cold air flooding of jet pump exit line.	6 in valve, 1570°F., on-off, for emergency flooding, fail open. Motor operated.
HCV-13	Manual operated valve to control I.D. fan temp. during normal operation.	8 in valve temp. up to 600°F. (at exit). Pressure drop at full open <1 in w.c.
HCV-14	Blast gate on air supply line for pollution control.	Blast gate 0.8 in pipe, Manual operated.

Pressure Control Valve--

Max. flow rate = 2000 lbs/hr
(445 scfm),
Max. temp. = 1572°F,
Max. pressure at inlet = 7 in w.c.,
Pressure drop at max. flow < 0.25 in w.c.,
Diameter = 10 in I.D.,
(See Fig. C-10, Item PCV-10).

Temperature Indicators--
(See Fig. C-10)

TI-18	Gas temp. at cold air, mixing plenum in preheater.	Range: up to 600°F.
TI-20	Gas temp. to I.D. fan.	Range: up to 600°F.

Flow Controller--
(See Fig. C-10)

FC-2	Hot gas flow contoller to preheater.	Input: mv or v (to be specified) Range: 0-10 in control, Output 120 VAC valve positioning, PB: 5-500%, Reset: 0.2-2 rpm, Rate: 0-1 min.

Temp. Controllers--
(See Fig. C-10)

TC-1	Gas temp. controller at exit of I.D. fan.	On-off controller with adjustable dead band 0-2000°F, Type K.
TC-11	Jet pump discharge temp. controller.	Input: Type K (chromel-alumel) thermocouple. Range: 0-2000°F, Control output: 120 VAC valve positioning. PB: 5-500%, Reset: 0.02-2 rpm, Rate: 0-1 min.
TCH-12	Jet pump discharge, high limit temp. controller.	On-off controller with adjustable dead band 0-2000° F., Type K.

Pressure Controller--
(See Fig. C-10).

PC-10	Jet pump discharge pressure controller.

Input: mv or v (to be specified),
Range: 0-10 in control,
Output: 120 VAC,
Valve position. PB: 5-500%,
reset: 0.02-2 rpm, Rate: 0-1 min.

Flow Indicators--
(See Fig. C-10).

FI-17	Primary flow indicator to jet pump.
FI-15	Air flow indicator for pollution control.
FI-13	Air flow indicator for I.D. fan temp. limitation.

Flow Rate Transmitter--
(See Fig. C-10).

FT-2	Hot gas, mass flow rate transmitter.	Input: 0-4000 pph, output 4-20 in ADC 14 in, orifice plate, R21 ring 6 in w.c., records mix gas flow and indicates gas temperature, 6 in thermocouple with well, type K, temperature compensated.

Temperature Elements--
(See Fig. C-10).

Specification.	Type K, wire size AWG 14 inconel protection tube, .18 in long.

Temp. Elements--

TE-5A. B, C, D,	Gas temp. at hot gas discharge plenum in preheater.
TE-4A, B, C, D	Gas temp. at four levels in preheater.
TE-9	Hot gas inlet temp. to preheater.
TE-18	Gas temp. at cold air mix plenum in preheater.
TE-1	Discharge gas temp. at exit of I.D. fan.
TE-9	Hot gas inlet temp. to preheater.
TE-11	Hot gas temp. at exit of jet pump (normal operation).
TE-12	Hot gas temp. at exit of jet pump (for emergency).
TE-20	Gas temp. to I.D. fan.

Temperature Recorders--
(See Fig. C-10).
15 points multipoint recorder type K-0-7000°F.

Temp. Recorders--

TR-9	Hot gas inlet temp. to preheater.
TR-5	Gas temp. at hot gas discharge plenum in preheater.
TR-4	Gas temp. at four levels in preheater.

Pressure Indicator--
(See Fig C-10).

PI-13	Jet pump primary pressure indicator. Range: 0-60 in w.c., 4 1/2 in dial size.

Pressure Transmitter--
(See Fig C-10)

PT-10	Jet pump discharge pressure transmitter. Range: -10 in to +10 in w.c., 4-20 ma output, built-in power supply, working temp. up to 2000° F.

Level Elements--
(See Fig. C-10)

LE-7A	High level element in cullet feed hopper.	Pellet's level in feed hopper, on-off only, max. temp. 1500°F
LE-7B	High-low level element in cullet feed hopper.	Pellet's level in feed hopper, on-off only, max temp. 1550°F.
LE-7C	Low-high level element in cullet feed hopper.	Pellet's level in feed hopper, on-off only, max. temp. 1500°F.

LE-7D	Low-low level element in cullet feed hopper.	Pellet's level in feed hopper, on-off only, max. temp. 1550°F.
LE-6A	High-high level element in charge hopper.	Pellet's level in charge hopper, temp.: ambient On-off only.
LE-6B	High-low level element in charge hopper.	Pellet's level in charge hopper, temp.: ambient On-off only.
LE-6C	Low-high level element in charge hopper.	Pellet's level in charge hopper, temp.: ambient On-off only.
LE-6D	Low-low level element in charge hopper.	Pellet's level in charge hopper, temp.: ambient on-off only.

Wiper Bar Control--
SY-8 Speed relay, for wiper bar motor speed control.

Batch Charger

Loose Batch & Cullet--
(See Fig. C-11)
Modified 18 in charger (insulated) and batch wetter.

Hot Pellets and Cullet--
(See Fig. C-12).
Modified 18 in charger (insulated),

Insulated transition chute to replace batch wetter during pellet and cullet feed.

Furnace

56 sq. ft.,
Direct fired,
Electric boosted.

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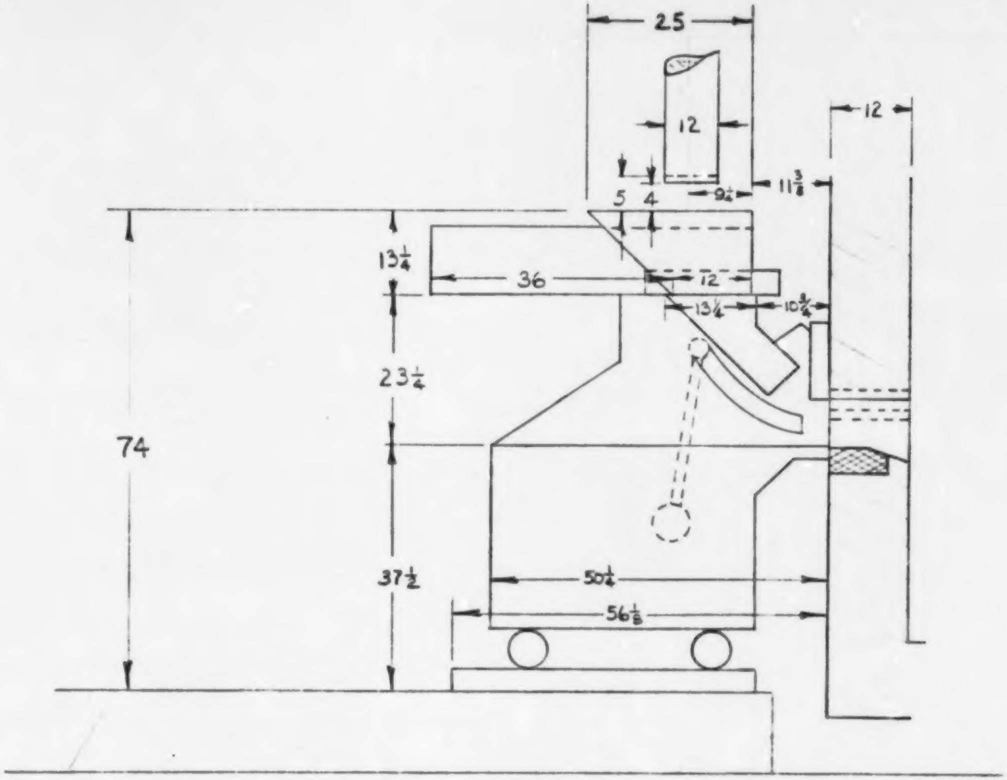
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12
12
11⅜
9¼
5
4
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36
12
13¼
10¾
23¼
74
37½
50¼
56⅛

Figure C 11. Loose batch charger.

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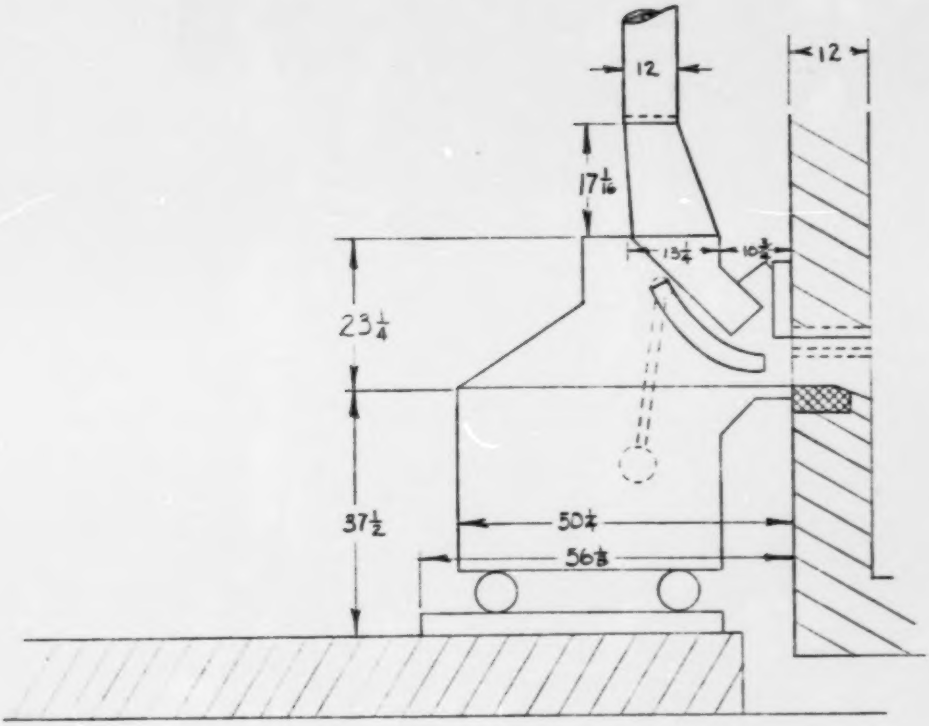
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37 1/2
50 1/4
56 1/8

Figure C 12. Hot pellet charger.

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APPENDIX D

ENERGY UTILIZATION - FUEL FIRED FURNACE

Using the general approach described in Appendix E, it is possible to utilize furnace data from one set of conditions and make reasonable predictions of the furnace heat balance for many other operating situations. The furnace structure losses for the base case furnace were estimated from emperical data for a similar size furnace. The oxide composition of the glass was used to calculate two factors from which the glass specific heat from 100 to 1600°C was calculated (See Table D-1). The calculation of stack loss is more complicated, but is possible because the volume of combustion air and combustion products is related to fuel input for stoichiometric conditions. Therefore, for predetermined combustion and temperature conditions, the sensible heat in the combustion air and products of combustion are known per cubic foot of natural gas used. With a few iterations of the program, the computer calculates the furnace fuel input that satisfies the heat balance requirements of the melt zone, regenerator/recuperator, and distribution zone. If auxiliary energy enters the system via the batch or electric boosting, the fuel requirements are decreased and a new heat balance is calculated. The key input variables are shown in Table D-1.

The results of the computer calculations are shown in Table D-2. On the bottom line is the glass furnace energy in Btu/ton x 10^6, which is the basis for the estimate of energy savings.

The material and energy balance for the Base 1 furnace is shown in simplified form in Figure D-1. For an output of 150 TPD, or 12,500 lbs/hr of glass, there is an input of 2500 lbs/hr of cullet (20 percent) and 11,500 lbs of batch materials. The latter produces 10,000 lbs of glass when melted. Values for the key furnace variables are found in Table D-1 and the computer output data are summarized in Table D-2. The energy balance portion of Figure D-1 shows a fuel input of 40.8 x 10^6 Btu/hr, with 10.9 x 10^6 Btu/hr going for glass melting, 13.5 x 10^6 Btu/hr to supply the structure heat losses, and 16.4 Btu/hr leaving the furnace via the stack gases. The computer program iterates until the heat balance for the melting zone, distributor, regenerator (or recuperator), and the total furnace system is satisfied. For a more detailed look at the heat flow into and out of each zone, please refer to Table D-3. While this level of detail is not needed for the purpose of this study, it does help to give a better perspective of where the furnace energy goes. Besides the

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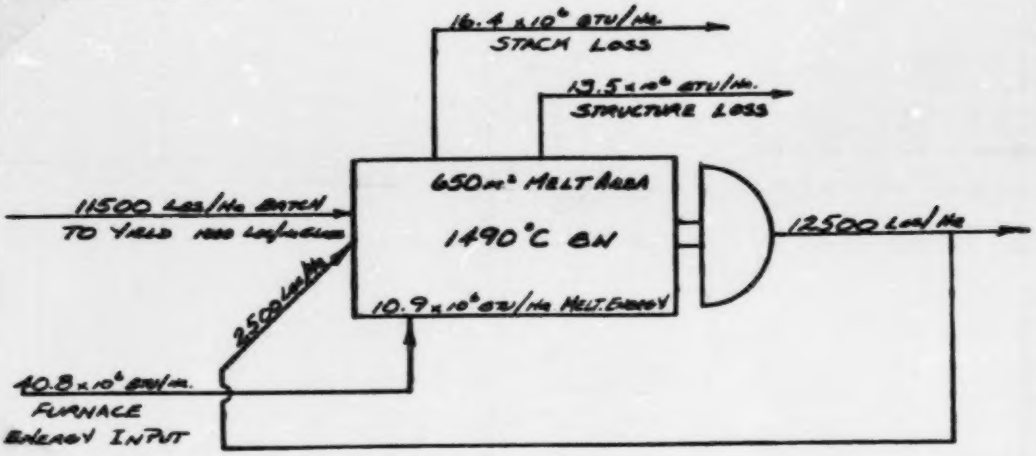
16.4 x 10^6 BTU/HR.
STACK LOSS
13.5 x 10^6 BTU/HR.
STRUCTURE LOSS
650 m² MELT AREA
1490°C BN
10.9 x 10^6 BTU/HR MELT. ENERGY
11500 LBS/HR BATCH
TO YIELD 1000 LBS/HR GLASS
2500 LBS/HR
40.8 x 10^6 BTU/HR.
FURNACE
ENERGY INPUT
12500 LBS/HR

Figure D-1. Furnace material and energy balance
150 ton/day (base[1]).

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TABLE D-1. COMPUTER INPUT DATA

Variable	Units	Base case regenerator 1	Base case regenerator 2	Scenarios Regenerator A	Scenarios Regenerator C	Scenarios Regenerator B	Scenarios Recuperator A'	Scenarios Recuperator C'	Scenarios Recuperator B'
Melt area	ft^2	650	1300	650	325	650	650	325	650
Pull rate	lbs/hr	12500	25000	12500	12500	25000	12500	12500	25000
Electric boost	kwh/hr	0	0	0	0	0	0	0	0
Max batch temp. in preheater	°C	--	--	800	800	800	800	800	800
Batch temp. to melter	°C	25	25	600	600	600	600	600	600
Comb air preheat temp.	°C	1000	1000	845	900	900	600	600	600
Waste gas temp-exit port	°C	1440	1440	1390	1440	1440	1390	1440	1440
Percent excess air	%	10	10	10	10	10	2	2	2
Percent heated comb air	%	92	92	92	92	92	100	100	100
Melt zone loss	10^6 Btu/hr	6.9	11.2	6.4	5.3	6.9	6.4	5.3	6.9
Regen/recup loss	10^6 Btu/hr	4.8	7.8	3.1	2.0	3.3	1.7	1.1	1.8
Distributor loss	10^6 Btu/hr	1.8	2.9	1.7	1.1	1.8	1.8	1.8	1.8
Furnace temp-base cond.	°C	1490	1490	1440	1490	1490	1440	1490	1490
Glass temp-out of furnace	°C	1375	1375	1325	1375	1375	1375	1375	1375
Glass specific HT Factor A	x10^4	5.095	5.095	5.095	5.095	5.095	5.095	5.095	5.095
Glass specific HT Factor B	x10^4	1748.	1748.	1748.	1748.	1748.	1748.	1748.	1748.
Glass chem-reaction energy	Btu/lb	200	200	200	200	200	200	200	200
Cullet ratio	%	20	20	20	20	20	20	20	20
Heat'g value-natural gas	Btu/lb	1010	1010	1010	1010	1010	1010	1010	1010
Stoich.	ft^3 air/ft^3 gas	9.66	9.66	9.66	9.66	9.66	9.66	9.66	9.66

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TABLE D-2. COMPUTER OUTPUT DATA

Variable	Units	Base case regenerator		Scenarios					
				Regenerator			Recuperator		
		1	2	A	C	B	A'	C'	B'
Melt area	sq ft	650	1300	650	325	650	650	325	650
Furnace fuel input	10^6 Btu/hr	40.8	73.0	34.8	30.5	52.0	32.1	29.5	50.6
Furnace loss	10^6 Btu/hr	13.5	21.9	11.2	8.4	12.0	9.8	7.5	10.5
Furnace stack loss	10^6 Btu/hr	16.4	19.3	16.3	14.4	24.6	14.9	14.3	24.7
Glass melting energy	10^6 Btu/hr	10.9	21.8	7.3	7.7	15.4	7.4	7.7	15.4
Sensible HT comb prod to regenerator	10^6 Btu/hr	28.5	50.6	23.6	21.5	36.7	20.2	19.2	32.8
Sensible HT-comb air to melter	10^6 Btu/hr	13.8	24.5	9.9	9.3	15.9	6.2	5.9	10.1
Port radiation-melter to regenerator	10^6 Btu/hr	5.1	8.1	4.7	3.1	5.0	1.5	1.1	1.7
Max sens HT batch in preheater	10^6 Btu/hr	0	0	3.8	3.8	7.6	3.8	3.8	7.6
Sens HT batch enter. melter	10^6 Btu/hr	0	0	2.7	2.7	5.4	2.7	2.7	5.4
Preheater batch reaction	10^6 Btu/hr	0	0	.5	.5	1.0	.5	.5	1.0
Energy to melter via batch	10^6 Btu/hr	0	0	3.2	3.2	6.4	3.2	3.2	6.4
Energy lost in filling	10^6 Btu/hr	0	0	1.1	1.1	2.2	1.1	1.1	2.2
Glass furn energy	10^6 Btu/ton	6.54	5.84	5.58	4.88	4.16	5.13	4.73	4.05

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TABLE D-3. BASE 1 FURNACE ENERGY BALANCE

Heat in	(Million Btu/hr)	Heat out	
	Melter		
Fuel	40.4	Sens. Ht - comb. gases	28.5
Power	--	Sens. Ht - batch gases	1.4
Sens. Ht-comb. air	13.8	Structure loss	6.9
Sens. Ht-batch	0	Port radiation	5.1
		Heat to dist.	12.3
Total in	54.2	Total out	54.2
	Distributor		
B.W. radiation	0.6	Structure loss	1.8
Glass sens. Ht	9.7	Glass sens. Ht	8.9
Glass chem. reactions	2.0	Glass chem. reactions	2.0
Fuel	0.4		
Total in	12.7	Total out	12.7
	Regenerator		
Sens. Ht-batch gases	28.5	Stack sens. ht	12.2
Sens. Ht-comb. gases	1.4	Stack lat. Ht H_2O	4.2
Port radiation	5.1	Structure loss	4.8
		Sens. Ht comb. air	13.8
Total in	35.0	Total out	35.0

structure losses, which is energy that is difficult to salvage, there is the sensible heat loss from the stack gas and the sensible heat loss from the glass leaving the distributor. This proposal addresses the waste sensible heat in the stack gases (12.2×10^6 Btu/hr), but does not examine the 8.9×10^6 Btu/hr of energy that must be dissipated in the glass cooling (forehearth), forming, and post-forming operations. This is technically a more difficult problem, but one which is being given attention at CORNING.

The material and energy balance for Scenario A is found in Figure D-2. The material balance is identical with the Base 1 furnace. The melt energy requirements have decreased for two reasons. The furnace temperature has dropped 50°C and the glass leaves the furnace at 1325°C instead of 1375°C. By referring to Table D-4, it can be seen that the glass specific heat dropped from 712 to 683 Btu/lb. For a pull of 12,500 lbs/hr, the sensible heat therefore drops from 8.9×10^6 Btu/hr to 8.5×10^6 Btu/hr. The chemical energy for melting is 200 Btu/lb and for the 10,000 lbs/hr of glass coming from batch, this totals 2×10^6 Btu/hr. The heat content of the glass leaving the furnace is then 10.5×10^6 Btu/hr for Scenario A and 10.9×10^6 Btu/hr for the Base 1 furnace. The furnace energy also decreases because 3.2×10^6 Btu/hr enters the furnace as batch preheat. From Table D-4, it can be seen that the batch at 600°C has a heat content of 268 Btu/lb. For 10,000 lbs/hr of glass from the batch, this totals 2.7×10^6 Btu/hr. With a quarter of the chemical reaction taking place in the preheater (50 Btu/lb), the total chemical reaction energy is 0.5×10^6 Btu/hr and the total energy in the preheated batch is 3.2×10^6 Btu/hr.

Although the furnace fuel input has decreased from the Base 1 furnace condition, the stack waste heat is about the same because of sealing and insulating the regenerators. Also, to get 800°C stack gases, a lower air preheat temperature (900°C instead of 1,000°C) was accepted. The quantity of energy in the stack gases is more than that needed for the batch drying and preheating. The use of some electrical boosting is a practiced method of further reducing the amount of fuel and stack waste energy.

Derived from similar calculations, the material and energy balance for Scenario C is shown in Figure D-3. As in Scenario A, it has been assumed that the preheated batch drops from 800°C to 600°C in the filling machine. This amounts to a heat loss of 1.1×10^6 BTU/hr. Attempts will be made to reduce this loss; however, the necessary equipment has not been completely designed; therefore, a conservative estimate has been used.

The material and energy balance for Scenario B is found in Figure D-4.

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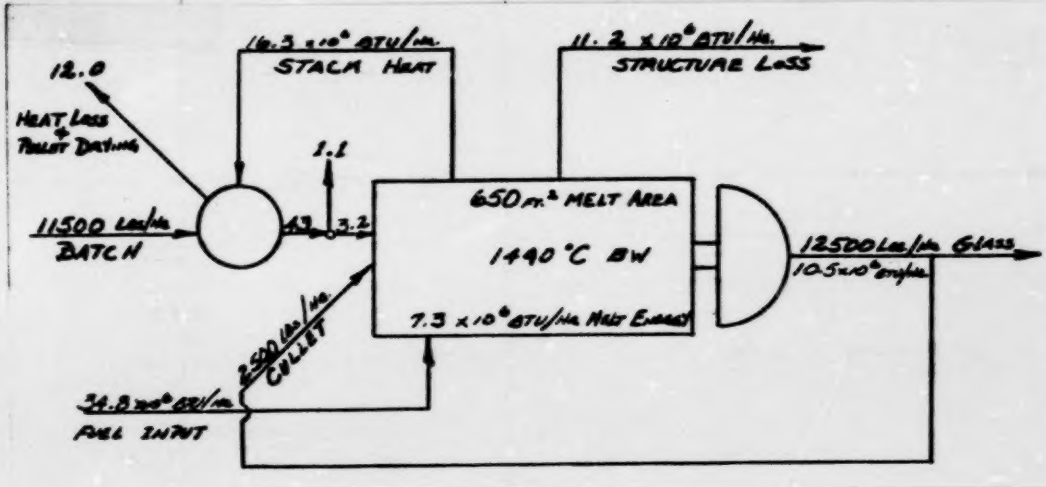
12.0
HEAT LOSS + PELLET DRYING
16.3 x 10⁶ BTU/HR.
STACK HEAT
11.2 x 10⁶ BTU/HR.
STRUCTURE LOSS
1.1
4.3
3.2
11500 LBS/HR
BATCH
650 FT.² MELT AREA
1440 °C BW
7.3 x 10⁶ BTU/HR MELT ENERGY
12500 LBS/HR GLASS
10.5 x 10⁶ BTU/HR
2500 LBS/HR
CULLET
34.8 x 10⁶ BTU/HR
FUEL INPUT

Figure D-2. Preheater and furnace material and energy balance scenario A 150 tons/day.

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TABLE D-4. SPECIFIC HEAT DATA FOR 838A SODA-LIME GLASS

Temperature (°C)	Specific heat BTU/Lb/°C	BTU/Lb from 25°C
100	0.3643	27
200	0.3941	69
300	0.4178	115
400	0.4372	164
500	0.4533	215
600	0.4669	268
700	0.4786	323
800	0.4887	379
900	0.4975	435
1000	0.5052	493
1100	0.5121	551
1200	0.5183	609
1300	0.5238	668
1325	0.5251	683
1350	0.5264	697
1375	0.5276	712
1400	0.5288	727
1425	0.5300	742
1450	0.5311	757
1475	0.5323	772
1500	0.5333	787

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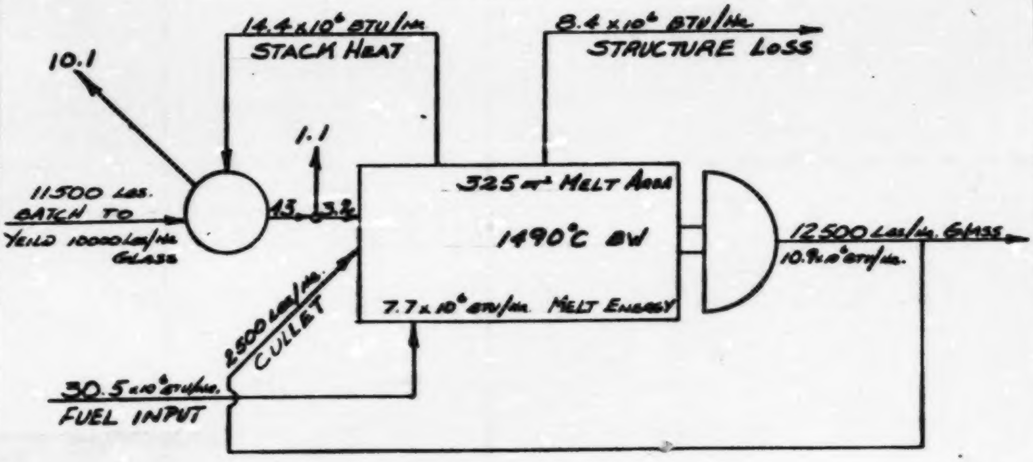
10.1
14.4 x 10⁶ BTU/HR.
STACK HEAT
8.4 x 10⁶ BTU/HR.
STRUCTURE LOSS
1.1
11500 LBS. BATCH TO YEILD 10000 LBS/HR. GLASS
4.3
3.2
325 m² MELT AREA
1490°C BW
7.7 x 10⁶ BTU/HR. MELT ENERGY
12500 LBS/HR. GLASS
10.9 x 10⁶ BTU/HR.
2500 LBS/HR. CULLET
30.5 x 10⁶ BTU/HR.
FUEL INPUT

Figure D-3. Preheater and furnace material and energy balance scenario C 150 tons/day.

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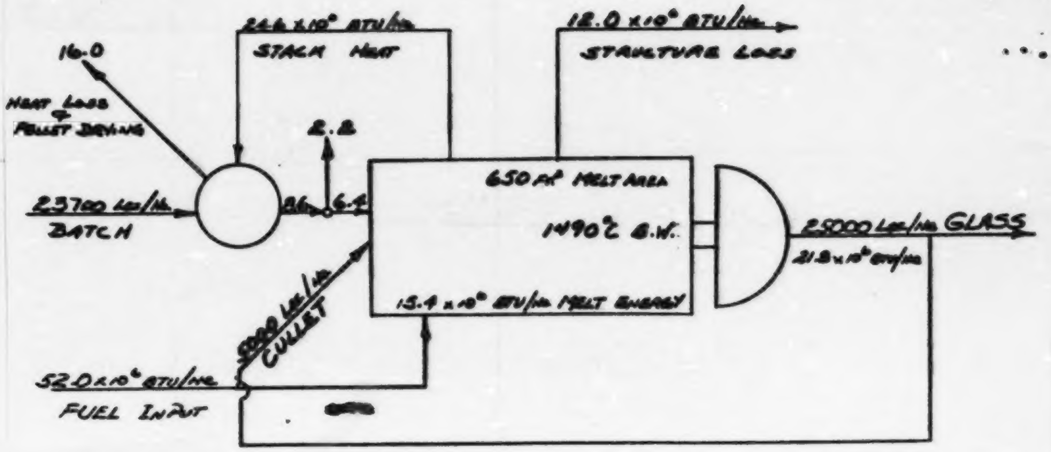
24.6 x10⁶ BTU/HR
STACK HEAT
16.0
HEAT LOSS & PELLET DRYING
2.2
23700 LBS/HR
BATCH
8.6
6.4
12.0 x10⁶ BTU/HR
STRUCTURE LOSS
650 ft² MELT AREA
1490°C B.W.
15.4 x10⁶ BTU/HR MELT ENERGY
5000 LBS/HR
CULLET
52.0 x10⁶ BTU/HR
FUEL INPUT
25000 LBS/HR GLASS
21.8 x10⁶ BTU/HR

Figure D-4. Preheater and furnace material and energy balance scenario B 300 tons/day.

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Appendix E

PREDICTING GLASS FURNACE ENERGY REQUIREMENTS WITH THE AID OF A HEAT BALANCE MODEL

George B. Boettner
Corning Glass Works
Corning, New York 14830

ABSTRACT

Stack heat loss data is a useful by-product of the emission measurements periodically made on glass furnaces. By combining this with other routine furnace data, a method for producing a macro furnace heat balance becomes the basis for a more detailed heat balance program which (with the aid of a mini-computer) can be used to predict the affect of several furnace variables on energy consumption. Cases discussed include the hypothetical substitution of a recuperator for a regenerator, and the increased use of electric power.

I. INTRODUCTION

The rising cost of energy and the growing urgency to conserve and utilize waste heat has put a responsibility on the Glass Industry to better understand its processes and take steps to improve thermal efficiencies. Since the largest single user of energy in the glass plant is typically the melting furnace, it becomes increasingly important that the melting process be understood from an energy balance point of view. An energy conservation program should start from an awareness of how much energy is being used and where the wasted energy is going.

Furnace energy balances are not new, but historically they have been rather laborious tasks and consequently, are done very infrequently. It is the author's experience that a simple, but accurate macro furnace heat balance can be made with data that already exist, or are easily obtainable. For some purposes, this may be all that is needed, but the macro balance can also become the base from which a more detailed furnace analysis is made.

In the example shown, a simultaneous heat balance was made around the three component parts of the furnace (melting zone, distributor, regenerator) and to do this, more furnace variables had to be considered. Not all of the data for these variables had been measured and assumptions had to be made until the macro furnace heat balance was satisfied. With the help of a mini-computer, these iterations could be done quickly. And by measuring key combustion variables, such as combustion air temperature, waste gas temperature and composition, the accuracy of the computer program was improved to the point that it could be used to predict the affect of changing furnace variables.

The case in point is a medium sized, cross-fired regenerative furnace melting a borosilicate glass at 8000 lbs/hour. The paper discusses the affect on energy consumption of a hypothetical improvement to the regenerator, its replacement with a recuperator, and the increased use of electric power.

II. THE MACRO FURNACE HEAT BALANCE

By limiting the furnace heat balance to a total energy input, and three output variables, the problem shrinks drastically in complexity. The heating value of fossil fuels and electric power is well known so the calculation of furnace energy input is easy and accurate. As shown in Figure 1, the other half of the energy equation can be limited to:

1. Stack heat loss
2. Glass melting energy
3. Structure heat loss

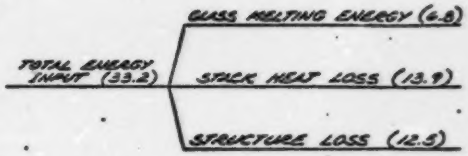

Figure 1. Borosilicate Glass Furnace Macro Heat Balance For a Production Rate of 8000 lb/hr @ 40% Cullet Ratio. Energy Data Are in Million BTU/hr.

Useful by-products of furnace stack emission measurements are the waste gas flow and temperature data from which a heat loss calculation can be made. Sampling ports have been gradually added to all of our furnace stacks and this has become a semi-routine measurement. It has "opened the door" to the macro furnace heat balance, because relatively accurate stack heat loss data are now available.

The energy required to convert raw materials to a glass is not yet a measured value. However, we have been using a calculated value for several years and have found it to be useful, particularly on electric melters. The technique for calculating the specific heat of a glass, based on its oxide composition, was demonstrated by Sharp & Ginther(1) many years ago and has now been summarized in the Handbook of Glass Manufacture(2). The mean specific heat of a typical lime glass (between room temperature and 2400°F) is about .3 BTU/lb/°F. While the bulk of "glass melting energy" is used in raising the glass/batch to the furnace temperature, a small amount is required to support the endothermic chemical reactions. This value is dependent upon the raw materials used. The value shown in The Handbook of Glass Manufacture(3) is 81 BTU/lb, whereas for our lime glasses, I have considered 165 BTU/lb of batch materials to be more typical. The point is, a useful and reasonably accurate estimate of glass melting energy is possible.

The remaining unknown in the macro furnace heat balance is the furnace structure loss, and it is obtainable by difference. This is by far the most complex and time consuming portion of the furnace heat balance, and it was by-passed completely for the macro balance.

III. FURNACE INPUT ENERGY VS. PRODUCTION RATES

There are times when furnace energy requirements at one production rate need to be estimated based on data at another rate. The concept of "no load energy" (sometimes called "holding heat") and "energy to fill" is a practical method, and it was implemented by making one adjustment to the macro heat balance data. For the borosilicate furnace, this step is represented by Figure 2, and it involved distributing two-thirds of the stack loss to "glass melting energy" and one-third to "structure loss". Admittedly, this was an educated estimate, but adequate for the initial purpose.

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The assumption for a specific furnace can be tested (and revised) with empirical furnace data if the range from minimum to maximum production rate is great enough, or if the opportunity arises to hold the furnace at "no load" for a day or so.

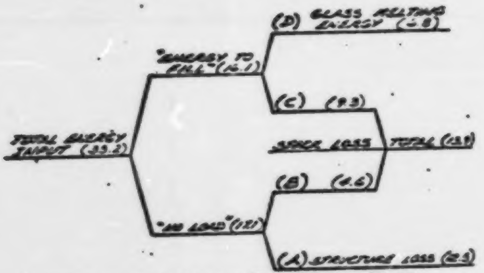
(D) GLASS MELTING ENERGY (6.8)
"ENERGY TO FILL" (16.1)
(C) (9.3)
TOTAL ENERGY INPUT (33.2)
STACK LOSS
TOTAL (13.9)
(B) (4.6)
"NO LOAD" (17.1)
(A) STRUCTURE LOSS (12.5)

Figure 2. Borosilicate Glass Furnace Macro Heat Balance Showing "Energy to Fill" and Furnace "No-Load Energy". Energy Data Are In Million BTU/hr For a Production Rate of 8000 lb/hr @ 40% Cullet.

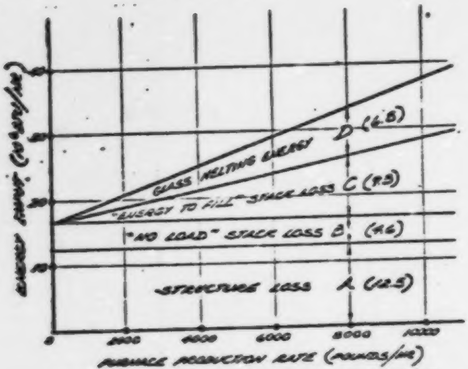

Figure 3. Energy Requirement Vs. Production Rate For a Fuel Fired Furnace

The data from Figure 2 were then put into the more general form, which is shown in Figure 3. In both figures, "A" represents the furnace structure loss and "A"+"B" is the furnace "no load". Both of these are essentially independent of furnace production rate, although there is a second order effect because furnace temperatures normally increase with higher pull rates. At 8000 lb/hr, the stack loss is "B"+"C", where "C" is the "energy to fill" component, and "D" is the "glass melting energy". Connecting the data points as shown provides the means for illustrating the affect of production rate on furnace energy input. In mathematical terms (for 1000 BTU/cu.ft. gas), the furnace fuel requirement could be expressed by:

$$Q = 17100 + (2.01 \times P)$$

Q = Total fuel (CFH)
P = Production Rate (Lbs/Hr)

IV. SUB-SYSTEM HEAT BALANCE

With the furnace macro heat balance data available, it became the base from which the furnace could be examined in more detail. This added more unknowns, but it also provided the opportunity to utilize more furnace data and to build a more complete "heat balance model" of the furnace. Even though many of the furnace variables had not been measured initially, it was possible to make educated assumptions, some of which had to be modified, in order to satisfy the macro heat balance shown in Figure 1.

The program was written so that a simultaneous heat balance could be made around each of the following furnace sub-systems:

A. Melt Zone - Bounded by the backwall, bridgewall and breastwall.
B. Distribution Zone - (Sometimes called the refiner.)
C. Regenerator - Which included the port necks and connecting flue system.

The boundaries were selected so that the same program could be used to simulate the use of a regenerator, a recuperator, or direct firing.

With a mini-computer, the iterations were done quickly to bring the sub-systems into balance. Assumed input variables also had to be modified until the sub-system heat balances were in agreement with the macro balance. Figure 4 shows the principal elements of energy flow between the sub-systems, as well as the total system heat balance data.

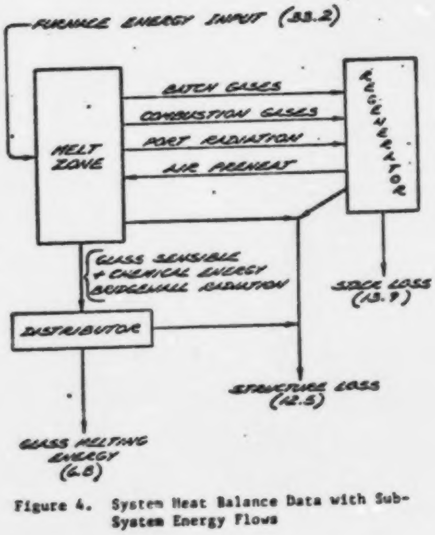
FURNACE ENERGY INPUT (33.2)
MELT ZONE
BATCH GASES
COMBUSTION GASES
PORT RADIATION
AIR PREHEAT
REGENERATOR
GLASS SENSIBLE
+ CHEMICAL ENERGY
BRIDGEWALL RADIATION
STACK LOSS
(13.9)
DISTRIBUTOR
STRUCTURE LOSS
(12.5)
GLASS MELTING
ENERGY
(6.8)

Figure 4. System Heat Balance Data with Sub-System Energy Flows

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V. FURNACE HEAT BALANCE RESULTS

Table I summarizes the furnace sub-system heat balances which were made by iterating the computer program, using the data from the regenerative furnace melting 8000 lb/hr of borosilicate glass.

The energy into the MELTER came from natural gas (at 1000 BTU/cu.ft.), the booster power (at 3413 BTU/KWH), and the sensible heat in the combustion air. The combustion calculations were based on 5% excess air, with 93% of the air being heated to 990°C. The other 7% of the air was believed to have entered the tank through the burner blocks and therefore was unheated. There was no sensible heat in the batch materials.

The single largest heat flow out of the MELTER was the sensible heat in the combustion gases. Since the volume of natural gas and air were defined, the heat content was calculable by assuming the gases exited through the ports at the MELTER temperature (1590°C). The sensible heat in the batch gases was based on the volume of gas evolved from the raw materials (CO_2, H_2O, etc.). The MELTER structure loss was initially obtained by subtracting the DISTRIBUTOR loss from the total, and splitting the difference between MELTER and REGENERATOR. This figure was sharpened by utilizing the furnace drawings to calculate the total surface area of the MELTER and REGENERATOR. The total area of each was subdivided into smaller areas over which the

HEAT IN	(Million BTU/Hr)	HEAT OUT	
MELTER			
Fuel	31.6	Sens.Ht.-Comb. Gases	23.7
Power	1.6	" " -Batch Gases	.1
Sens. Ht.-Air	10.3	Structure Loss	6.2
" " -Batch	0.0	Port Radiation	5.3
		Heat to Dist.	8.2
TOTAL IN	43.5	TOTAL OUT	43.5
DISTRIBUTOR			
B.W. Radiation	.9	Structure Loss	1.4
Glass Sens. Ht.	6.6	Glass Sens. Ht.	6.1
" Chem. Reaction	.7	" Chem. Reaction	.7
Fuel	0.0		
TOTAL IN	8.2	TOTAL OUT	8.2
REGENERATOR			
Sens.Ht.-Batch Gases	.1	Stack Sens. Ht.	10.6
" " -Comb. Gases	23.7	" Latent Ht.	3.3
Port Radiation	5.3	Structure Loss	4.9
		Sens. Ht. Comb. Air	10.3
TOTAL IN	29.1	TOTAL OUT	29.1

Table 1 Furnace Sub-Systems Heat Balance

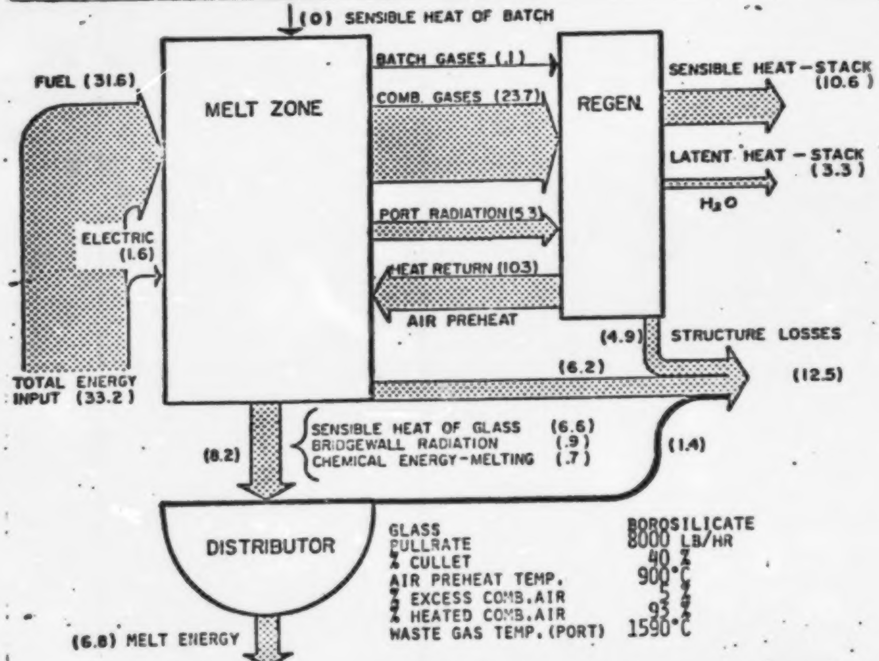
(0) SENSIBLE HEAT OF BATCH
FUEL (31.6)
MELT ZONE
BATCH GASES (.1)
COMB. GASES (23.7)
REGEN.
SENSIBLE HEAT - STACK (10.6)
LATENT HEAT - STACK (3.3)
H_2O
PORT RADIATION (5.3)
ELECTRIC (1.6)
HEAT RETURN (10.3)
AIR PREHEAT
(4.9)
STRUCTURE LOSSES
(6.2)
(12.5)
TOTAL ENERGY INPUT (33.2)
SENSIBLE HEAT OF GLASS (6.6)
BRIDGEWALL RADIATION (.9)
CHEMICAL ENERGY-MELTING (.7)
(8.2)
(1.4)
DISTRIBUTOR
GLASS BOROSILICATE
PULLRATE 8000 LB/HR
% CULLET 40 %
AIR PREHEAT TEMP. 900°C
% EXCESS COMB.AIR 5 %
% HEATED COMB.AIR 93 %
WASTE GAS TEMP.(PORT) 1590°C
(6.8) MELT ENERGY

FIGURE 5
GLASS TANK HEAT BALANCE
(MILLION BTU/HOUR)

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heat loss could be averaged. Using both optical pyrometer (inside temperature) and contact pyrometer measurements (outside temperature), representative heat loss calculations were made.

The summation of this data, along with losses from furnace openings, provided the basis for the final distribution of structure losses. The figure for "port radiation" initially came out of the iterative process as a number which was required to satisfy the system heat balance. After an independent calculation (by a heat transfer specialist) yielded a value which was almost the same, it was concluded this was a reasonable and logical figure. The heat transfer to the DISTRIBUTOR, which is by both radiation and convection, is discussed further in the next paragraph. Thus, we had a total energy transfer both in and out of the MELT ZONE of 43.5 million BTU/hour.

The glass flow through the DISTRIBUTOR (8000 lbs/hour) gave up 105°C, and thus accounted for .5 x 10^6 BTU/hr of energy. The heat radiated over the shadow wall was calculated at .9 x 10^6 BTU/hour. The chemical reaction energy remained as an irretrievable portion of the glass melting energy. Since the net energy into the DISTRIBUTOR was 1.4 x 10^6 BTU/hour, the structure loss had to be the same. The total heat in and out came to 8.2 x 10^6 BTU/hour.

The energy interchange between the REGENERATOR and the MELTER has already been mentioned, and the heat to the stack was initially defined by the macro balance. The REGENERATOR structure loss, which required some measurements to sharpen the original estimate, became important when the program was used to hypothesize the substituting of a recuperator for the regenerator, and when increased amounts of "booster" power were used to replace fuel. The total heat passing through the REGENERATOR totaled 29.1 x 10^6 BTU/hr.

Figure 5 shows the completed furnace heat balance in the format suggested in Figure 4 and using the data from Table 1. At this stage, we had a heat balance model which was in good agreement with the available data from the borosilicate furnace being studied. The next step was to change input variables and iterate the program to a new heat balance, and thereby get an estimate of the furnace fuel requirements under a new set of conditions. A brief discussion of three examples follows.

VI. HIGHER AIR PREHEAT TEMPERATURES WITH THE REGENERATOR

We assumed that by better sealing and insulating the flues, ports and regenerator chambers, along with eliminating most of the "cold" air being inspirated around the burner tips, the air preheat temperature could be increased to 1200°C. The heat balance that resulted from these assumptions is shown in Column VI of Table 2. The only change in input data from the previous condition (shown in Column 5 of Table 2) was the air preheat temperature (990°C → 1200°C), the percent heated combustion air (93% → 98%) and the regenerator structure loss (4.9 → 3.2 x 10^6 BTU/hr). The resulting balance showed the sensible heat in the combustion air to have increased 11% (+1.1 x 10^6 BTU/hr) with the fuel decreasing by 14% (-4.4 x 10^6 BTU/hr).

COLUMN	V Base Cond.	VI Improved Regen.	VII Recup.	VIII Hi Boost
Combustion Assumptions:				
Air Preheat Temp. (°C)	990	1200	600	990
Percent Excess Air	5%	5%	2%	5%
Percent Heated Comb. Air	93%	98%	100%	93%
Energy Data: (10^6 BTU/Hr)				
Melt Zone Input:				
Fuel	31.6	27.2	28.5	11.8
Power	1.6	1.6	1.6	9.5
Comb. Air-Sens. Heat	10.3	11.4	5.5	3.8
TOTAL	43.5	40.2	35.6	25.1
Melt Zone → Distributor:				
Glass Sens. Heat	6.6	6.6	6.6	6.6
Glass Chemical Energy	.7	.7	.7	.7
Bridgewall Radiation	.9	.9	.9	.9
TOTAL	8.2	8.2	8.2	8.2
Melt Zone → Regen./Recup.:				
Batch Gases Sens. Heat	.1	.1	.1	.1
Comb. Gases " "	23.7	20.4	19.9	8.8
Port Radiation	5.3	5.3	1.2	1.8
TOTAL	29.1	25.8	21.2	10.7
Structure Loss:				
Melter	6.2	6.2	6.2	6.2
Distributor	1.4	1.4	1.4	1.4
Regen./Recup.	4.9	3.2	1.8	1.7
TOTAL	12.5	10.8	9.4	9.3
Stack Loss:				
Sensible Heat	10.6	8.4	11.1	4.0
Latent Heat-H_2O	3.3	2.8	2.8	1.2
TOTAL	13.9	11.2	13.9	5.2
Glass Melting Energy	6.8	6.8	6.8	6.8

Table 2 Heat Balance Data

VII. REPLACING THE REGENERATOR WITH A RECUPERATOR

Furnace regenerators are known to give a higher air preheat temperature than metallic recuperators, and are generally conceded to be the preferred system of heat recovery. However, a closer look at the advantages of each system, in the light of utilizing the higher grade of waste heat, showed the recuperator to be a better candidate than initially assumed.

Column VII of Table 2 shows the heat balance for the same furnace, except with a metallic recuperator being used. The air preheat temperature was assumed to be 600°C, a conservative estimate for most metallic recuperators. However, the burners would be "sealed-in" and there would be no "reversal" process so tighter combustion conditions could be expected. The percent excess air could logically be reduced (5% → 2%), and the percent heated combustion air increased (93% → 100%). Because the number of ports could be reduced from eight to a minimum of two and possibly one, the total port area has been presumed to decrease by a factor of 4.4. This substantially reduced the MELT zone loss attributed to "port radiation". Calculations indicated that the heat loss of the recuperator would be significantly lower than the regenerator.

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The predictions (Column VII, Table 2) indicated a fuel consumption which would be lower than the regenerator with 990°C air preheat (Column V, Table 2), and slightly higher than the improved regenerator with 1200°C air preheat (Column VI, Table 2). The total structure loss has decreased and the quantity and grade of heat loss from the stack has increased. Although only an estimate, the temperature of the stack waste gas should be in the range of 800°C with the recuperator, as compared with 400°C for the regenerative system. This factor becomes significant when a systems approach is used and a serious attempt is made to utilize the furnace waste heat.

VIII. REPLACING FUEL WITH ELECTRIC POWER

Another use for the heat balance program has been to predict the decrease in fuel consumption that could result from an increase in electric boosting. The basic assumption made is that "port radiation" and regenerator structural losses decrease with increasing amounts of electric boosting. The results of a simulated 7.9 million BTU/hr (2315 KW) increase in electric boosting (1.6 → 9.5 x 10^6 BTU/hr) are shown in Column VIII of Table 2. By comparing with the "base condition" data in Column V, it can be seen that the fuel decreased 19.8 x 10^6 BTU/hr (31.6 → 11.8 x 10^6 BTU/hr). Therefore, for this particular furnace, a 1 BTU increase in electric power should result in a 2.5 BTU reduction in fuel. This energy ratio factor should not be considered as representing all glass furnaces, but it may be typical of many. It is known to be higher for some furnaces, in which case more electric boosting is economically attractive. The key point is that with energy prices continually changing, it is important to have at least a ballpark estimate of the ratio factor for each electrically boosted furnace. The heat balance model can be helpful in this regard.

IX. CONCLUSIONS

1. Rather than initiating a complex furnace heat balance that has little use until completed, this study exemplified the philosophy of starting with a simple solution and adding complexity as required.

2. An accurate macro heat balance was done from data that for the most part already existed. From the macro balance the following was achieved:

   2.1 Identified the amount and grade of waste heat leaving the furnace.

   2.2 Helped to define the furnace "energy to fill" and "no load energy" (holding heat).

   2.3 Provided the base for making a simultaneous sub-system heat balance which was iterated until it agreed with the macro furnace heat balance.

3. This resulted in a relatively simple furnace heat balance program which, when iterated to agree with known furnace conditions, was used to predict energy requirements over a range of furnace conditions.

4. The program indicated that the furnace with a metallic recuperator could compete with the regenerative furnace (from an energy point of view), and had some advantages when considering the utilization of waste heat.

5. For the furnace being studied, it was shown that one BTU of electric power could replace 2½ BTU's of fuel.

X. REFERENCES

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